"Preliminary Report of the Scientific Exploration of the Deep Sea in H.M. Surveying-vessel 'Porcupine,' during the Summer of 1869," conducted by Dr. CARPENTER, V.P.R.S., Mr. J. GWYN JEFFREYS, F.R.S., and Prof. WYVILLE THOMSON, LL.D., F.R.S. Received November 18, 1869.

PART I.

INTRODUCTION.

PRELIMINARY PROCEEDINGS.

The following Extracts from the Minutes of the Council of the Royal Society set forth the origin of the 'Porcupine' Expedition, and the objects which it was designed to carry out.

January 21, 1869.

The Preliminary Report of the Dredging Operations conducted by Drs. Carpenter and Wyville Thomson (in the 'Lightning') having been considered, it was

Resolved,—That, looking to the valuable results obtained from these Marine Researches, restricted in scope as they have been in a first trial, the President and Council consider it most desirable, with a view to the advancement of Zoology and other branches of science, that the exploration should be renewed in the course of the ensuing summer, and carried over a wider area; and that the aid of Her Majesty's Government, so liberally afforded last year, be again requested in furtherance of the undertaking.

Resolved,—That a Committee be appointed to report to the Council on the measures it will be advisable to take in order to carry the foregoing resolution most advantageously into effect. The Committee to consist of the President and Officers, with Dr. Carpenter, Mr. Gwyn Jeffreys, and Captain Richards.

February 18, 1869.

Read the following Report of the Committee on Marine Researches:—

"The Committee appointed by the Council on the 21st of January, to consider the measures advisable for the further prosecution of Researches into the Physical and Biological Conditions of the Deep Sea in the neighbourhood of the British Coast, beg leave to Report as follows:—

"The results obtained by the Dredgings and Temperature-Soundings carried on during the brief Cruise of H.M.S. 'Lightning' in August and September 1868, taken in connexion with those of the Dredgings recently prosecuted under the direction of the Governments of Sweden and of the United States, and with the remarkable Temperature-Soundings of Captain Shortland in the Arabian Gulf, have conclusively shown—

"1. That the Ocean-bottom, at depths of 500 fathoms or more, presents a vast field for research, of which the systematic exploration can scarcely fail to yield results of the highest interest and importance, in regard alike to Physical, Biological, and Geological Science.

"2. That the prosecution of such a systematic exploration is altogether beyond the reach of private enterprise, requiring means and appliances which can only be furnished by Government.

"It may be hoped that Her Majesty's Government may be induced at some future time to consider this work as one of the special duties of the British Navy; which possesses, in the world-wide distribution of its Ships, far greater opportunities for such researches than the Navy of any other country.

"At present, however, the Committee consider it desirable that the Royal Society should represent to Her Majesty's Government the importance of at once following up the suggestions appended to Dr. Carpenter's 'Preliminary Report' of the Cruise of the 'Lightning,' by instituting, during the coming season, a detailed survey of the deeper part of the Ocean-bottom between the North of Scotland and the Faroe Islands, and by extending that survey in both a N.E. and a S.W. direction, so as thoroughly to investigate the Physical and the Biological conditions of the two Submarine Provinces included in that area, which are characterized by a strongly marked contrast in Climate, with a corresponding dissimilarity in Animal Life, and to trace this climatic dissimilarity to its source; as well as to carry down the like survey to depths much greater than have been yet explored by the Dredge.

"This, it is believed, can be accomplished without difficulty (unless the weather should prove extraordinarily unpropitious) by the employment

of a suitable vessel, provided with the requisite appliances, between the middle of May and the middle of September. The Ship should be of sufficient size to furnish a Crew of which each 'watch' could carry on the work continuously without undue fatigue, so as to take the fullest advantage of calm weather and long summer days; and should also provide adequate accommodation for the study of the specimens when freshly obtained, which should be one of the primary objects of the Expedition. As there would be no occasion to extend the Survey to a greater distance than (at the most) 400 miles from land, no difficulty would be experienced in obtaining the supplies necessary for such a four months' cruise, by running from time to time to the port that might be nearest. Thus, supposing that the Ship took its departure from Cork or Galway, and proceeded first to the channel between the British Isles and Rockall Bank, where depths of from 1000 to 1300 fathoms are known to exist, the Dredgings and Temperature-Soundings could be proceeded with in a northerly direction, until it would be convenient to make Stornoway. Taking a fresh departure from that port, the exploration might then be carried on over the area to the N.W. of the Hebrides, in which the more moderate depths (from 500 to 600 fathoms) would afford greater facility for the detailed survey of that part of the Ocean-bottom on which a Cretaceous deposit is in progress—the Fauna of this area having been shown by the 'Lightning' researches to present features of most especial interest, while the careful study of the deposit may be expected to elucidate many phenomena as yet unexplained which are presented by the ancient Chalk Formation. A month or six weeks would probably be required for this part of the Survey, at the end of which time the vessel might again run to Stornoway for supplies. The area to the North and N.E. of Lewis should then be worked in the like careful manner; and as the 'cold area' would here be encountered, special attention should be given to the determination of its boundaries, and of the sources of its climatic peculiarity. These would probably require the extension of the survey for some distance in a N.E. direction, which would carry the vessel into the neighbourhood of the Shetland Isles; and Lerwick would then be a suitable port for supplies. Whatever time might then remain would be advantageously employed in dredging at such a distance round the Shetlands as would give depths of from 250 to 400 fathoms, Mr. Gwyn Jeffreys's dredgings in that locality having been limited to 200 fathoms.

"The Natural-History work of such an Expedition should be prosecuted under the direction of a Chief (who need not, however, be the same throughout), aided by two competent Assistants (to be provided by the Royal Society), who should be engaged for the whole Cruise. Mr. Gywn Jeffreys is ready to take charge of it during the first five or six weeks, say, to the end of June, when Professor Wyville Thomson would be prepared to take his place; and Dr. Carpenter would be able to join the Expedition early in August, remaining with it to the end. It would be a great ad-

vantage if the Surgeon appointed to the Ship should have sufficient knowledge of Natural History, and sufficient interest in the inquiry, to participate in the work.

"The experience of the previous Expedition will furnish adequate guidance as to the appliances which it would be necessary to ask the Government to provide, in case they accede to the present application.

"With reference to the Scientific instruments and apparatus to be provided by the Royal Society, the Committee recommend that the detailed consideration of them be referred to a Special Committee, consisting of Gentlemen practically conversant with the construction and working of such instruments."

Resolved,—That the Report now read be received and adopted, and that application be made to Her Majesty's Government accordingly.

The following Draft of a Letter to be transmitted by the Secretary to the Secretary of the Admiralty was approved:—

"The Royal Society,
Burlington House,
February 18, 1869.

"Sir,—Referring to the 'Preliminary Report' by Dr. Carpenter of the Results of the Deep-Sea Exploration carried on during the brief cruise of Her Majesty's Steam-vessel 'Lightning' in August and September last, which has already been transmitted for the consideration of the Lords Commissioners of the Admiralty—I am directed by the President and Council of the Royal Society to state that, looking to the valuable information obtained from these Marine Researches, although comparatively restricted in duration and extent, they deem it most desirable, in the interests of Biological and Physical Science, and in no small degree also for the advancement of Hydrographical knowledge, that a fresh exploration should be entered upon in the ensuing summer, and extended over a wider area; and they now desire earnestly to recommend the matter to the favourable consideration of My Lords, in the hope that the aid of Her Majesty's Government, which was so readily and liberally bestowed last year, may be afforded to the undertaking now contemplated, for which such support would be indispensable.

In favour of the practicability and probable success of the proposed fresh exploration, I am directed to explain that the objects to be aimed at, as well as the course to be followed and the measures to be employed for their attainment, have mainly been suggested by the observations made and the experience gained in the last Expedition.

"Further information as to the proposed exploration will be found in the Report, herewith transmitted, of a Committee to whose consideration the subject was referred by the Council.

"It is understood that the requisite Scientific Apparatus and the remuneration of the Assistants to be employed would be provided by the

Royal Society. With regard to the appliances which Her Majesty's Government may be asked to provide, the experience of the previous expedition will furnish adequate guidance, whenever the general scheme may be approved. It has appeared to the President and Council, that if the ship required for the proposed service could be provided by the temporary employment of one of Her Majesty's Surveying Vessels now in commission, anything beyond a trifling outlay on the part of the Government would be rendered unnecessary. "I remain,

"Your obedient Servant,

"W. Sharpey, M.D.,

"*The Secretary to the Admiralty.*" *Sec. R.S.*"

Resolved,—That a Committee be appointed to consider the Scientific Apparatus it will be desirable to provide for the proposed Expedition. The Committee to consist of the President and Officers, with Dr. Carpenter, Captain Richards, Mr. Siemens, Dr. Tyndall, and Sir Charles Wheatstone, with power to add to their number.

That a sum of £200 from the Government Grant be assigned to Dr. Carpenter for the further prosecution of Researches into the Temperature and Zoology of the Deep Sea.

March 18, 1869.

An oral communication was made by the Hydrographer to the effect that the Lords Commissioners of the Admiralty had acceded to the request conveyed in Dr. Sharpey's letter of Feb. 18; that H.M. Surveying-vessel 'Porcupine' had been assigned for the service; and that the special equipment needed for its efficient performance was proceeding under the direction of her Commander, Capt. Calver.

April 15, 1869.

Read the following Letter from the Admiralty:—

"Admiralty, 19 March, 1869.

"Sir,—With reference to previous correspondence, I am commanded by My Lords Commissioners of the Admiralty to acquaint you that Dr. Carpenter and his Assistants, who have been deputed by the Royal Society to accompany the Expedition about to be dispatched to the neighbourhood of the Faroe Isles for the purpose of investigating the bottom of the Ocean by means of deep-sea soundings, will be entertained whilst embarked on board the 'Porcupine' ‹ the Government expense.

"I am, Sir,

"Your obedient Servant,

"W. G. Romaine."

"*The President of the Royal Society.*"

June 17, 1869.

Read the following Report:—

"The Committee appointed Feb. 18, 1869, to consider the Scientific

Apparatus it will be desirable to provide for the proposed Expedition for Marine Researches, beg leave to lay before the Council the following Report:—

"The chief subjects of Physical Enquiry which presented themselves as interesting on their own account, or in relation to the existence of Life at great depths, were as follows:—

"(1) The Temperature both at the bottom and at various depths between that and the surface.

"(2) The nature and amount of the dissolved Gases.

"(3) The amount of Organic matter contained in the water, and the nature and amount of the Inorganic salts.

"(4) The amount of Light to be found at great depths.

"Among these subjects the Committee thought it desirable to confine themselves in the first instance to such as had previously to some extent been taken in hand, or could pretty certainly be carried out.

"The determination of Temperatures has hitherto rested chiefly upon the registration of *minimum* Thermometers. It is obvious that the temperature registered by minimum thermometers sunk to the bottom of the sea, even if their registration were unaffected by the pressure, would only give the lowest temperature reached *somewhere* between top and bottom, not *necessarily* at the bottom itself. The temperatures at various depths might indeed, provided they nowhere increased on going deeper, be determined by a series of minimum thermometers placed at different distances along the line, though this would involve considerable difficulties. Still, the liability of the index to slip, and the probability that the indication of the thermometers would be affected by the great pressure to which they were exposed, rendered it very desirable to control their indications by an independent method.

"Two plans were proposed for this purpose, one by Sir Charles Wheatstone, and one by Mr. Siemens. Both plans involved the employment of a voltaic current, excited by a battery on deck; and required a cable for the conveyance of insulated wires. The former plan depended upon the action of an immersed Breguet's thermometer, which by an electro-mechanical arrangement was read by an indicating instrument placed on deck. The latter plan made the indication of temperature depend on the existence of a thermal variation in the electric resistance of a conducting wire. It rested on the equalization of the derived currents in two perfectly similar partial circuits, containing each a copper wire running the whole length of the cable, the sea, and a resistance-coil of fine platinum wire; the coil in the one circuit being immersed in the sea at the end of the cable, and that in the other being immersed in a vessel on deck, containing water the temperature of which could be regulated by the addition of hot or cold water, and determined by an ordinary thermometer.

"The instruments required in Sir Charles Wheatstone's plan were more expensive, and would take longer to construct; and besides, the Com-

mittee were unwilling to risk the loss of a somewhat costly instrument in case the cable were to break. On these accounts they thought it best to adopt the simpler plan proposed by Mr. Siemens; and the apparatus required for carrying the plan into execution is now completed, and in use in the expedition.

"Meanwhile a plan had been devised by Dr. Miller for obviating the effect of pressure on a minimum thermometer, without preventing access to the stem for the purpose of setting the index. It consists in enclosing the bulb in an outer bulb rivetted-on a little way up the stem, the interval between the bulbs being partly filled with liquid, for the sake of quicker conduction. The Committee have had a few minimum thermometers constructed on this principle, which have been found to answer perfectly. The method is described in a short paper which will be read to the Society to-morrow.

"For obtaining specimens of water from any depth to which the dredging extends, the Committee have procured an instrument constructed as to its leading features on the plan of that described by Dr. Marcet in the Philosophical Transactions for 1819, and used successfully in the earlier northern expeditions.

"Mr. Gwyn Jeffreys is now out on the first cruise of the 'Porcupine,' the vessel which the Admiralty have sent out for the purpose, and is accompanied by Mr. W. L. Carpenter, B.Sc. (son of Dr. Carpenter), who undertakes the general execution of the physical and chemical part of the inquiry. A letter has been received by the President from Mr. Jeffreys, who speaks highly of the zeal and efficiency of Mr. Carpenter. The thermometers protected according to Dr. Miller's plan, and the instrument for obtaining specimens of water from great depths, have been found to work satisfactorily in actual practice. Mr. Siemens's instrument was not quite ready when the vessel started on her first cruise, and was not on board when the above letter was written. The gas-analyses have been successfully carried on, notwithstanding the motion of the vessel. From a letter subsequently received from Mr. Carpenter, it appears that Mr. Siemens's apparatus, so far as it has as yet been tried, works in perfect harmony with the thermometers protected according to Dr. Miller's plan."

"June 16, 1869."

Resolved,—That the Report now read be received and entered on the Minutes.

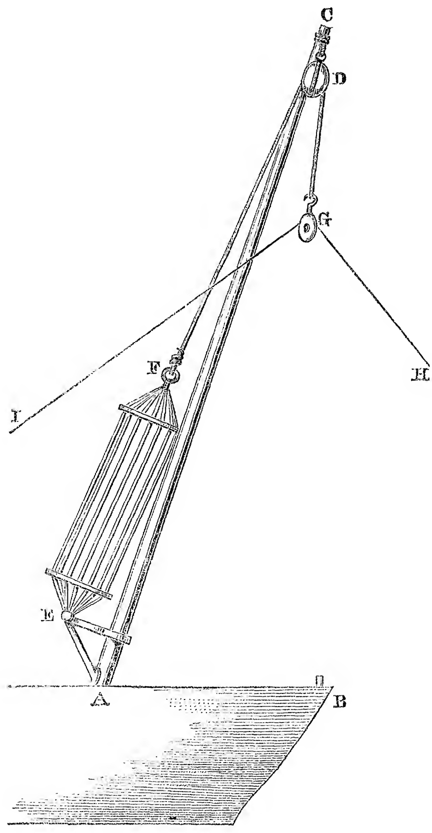
Equipment.

1. The equipment of the 'Porcupine' for the purposes of Deep-sea Sounding and Dredging was devised on the basis of the experience gained in previous Deep-sea Sounding Voyages (especially in that of the 'Hydra'*),

* Sounding Voyage of H.M.S. 'Hydra,' Captain P. R. Shortland, 1868; also Notes on Deep-Sea Soundings, by Staff-Commander Davis, 1867.

and in the 'Lightning' Expedition.—As it was considered advisable by Capt. Calver that provision should be made for carrying on Sounding and Dredging at either end of the ship, a "derrick" (A C) with an "accumulator" * (E F) was rigged out both at the bow and the stern, on the plan shown in the accompanying figure.

Fig. 1.



* The Accumulator is composed of a number of strong vulcanized India-rubber springs combined at their extremities E F; and its use is twofold,—*first*, to indicate by its elongation any excessive strain upon the sounding or dredging line I H, which passes through the block G; and *second* to ease off the suddenness of such strain, and give time for the action by which it may be relieved. This is especially valuable in Deep-sea Sounding and Dredging when the vessel is pitching; for the friction of two or three miles of immersed line is so great as to prevent its yielding to any sudden jerk, such as that given to its attached extremity by a vertical motion of a few feet when the vessel rises to a sea. And it is absolutely needful when Dredging is carried on from a vessel as large as the 'Porcupine'; since, whenever the dredge 'fouls,' the momentum of such

2. An ample supply of Sounding-line was provided, specially manufactured for the purpose; this line, made of the best Italian hemp, although no more than 0·8 inch in circumference, bears a strain of 12 cwt. For Soundings within 1000 fathoms' depth, it was found most convenient to employ an ordinary cylindrical Deep-sea Lead weighing 1 cwt., having at its base a conical cup for bringing up mud or sand from the bottom, which is furnished with a circular lid that falls down and closes it in when the lead strikes.—Above the Lead a Water-bottle (§ 19) was attached to the line, by which a sample of sea-water could be brought up from the bottom or from any intermediate depth. And above this again there were attached two or more Thermometers, enclosed in cylindrical copper cases having holes at the top and bottom through which the sea-water streams upwards as the lead descends.

3. The Sounding-lead with its appurtenances is allowed to descend as rapidly as it can carry out the line; but instead of descending at a constantly accelerating rate, it requires more time for every additional 100 fathoms; this retardation being due, not, as is popularly supposed, to an increase in the density of the water*, but to the friction of the sounding-line in its descent, which of course increases with every additional fathom that runs out. It is this friction that produces the chief strain upon the line when the Lead is being drawn up, and renders great caution requisite in regulating the rate of the reeling-in which is effected by the donkey-engine.

4. For the deeper Soundings, the 'Hydra' Apparatus was employed. The essential principle of this is the same with that of all the other forms of Deep-sea Sounding apparatus now in use; the weights or sinkers being so attached as to be let go by a mechanical contrivance when it touches the bottom, so that the line is relieved from the duty of raising them to the surface,—the rod or tube alone, with the water-bottle and thermometers, being brought up by it. For Soundings at depths of from 1000 to 1500 fathoms, *two* sinkers, each of 112 lbs., were employed; and for yet deeper soundings *three* were used. The peculiarity of the 'Hydra' apparatus consists partly in the mechanical contrivance for the detachment of the sinkers; and partly in the construction of the rod which carries them, this being a strong tube furnished with valves that open upwards, so as to allow the water to stream through it freely in its descent, whilst they enclose the mud or sand into which the tube is forced on striking the bottom before the sinker is detached†.

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a vessel, however slowly it might be moving through the water, would cause the dredge-line to part, if the strain were sudden instead of gradual.

* This is so trifling, even at 2½ *miles depth*, as not to equal the difference in density between fresh and salt water; being estimated by Dr. Miller at certainly not more than 1-47th of its volume, whilst sea-water of sp. gr. 1·027 is 1-37th heavier than fresh water.

† A detailed account of this Apparatus will be found in the "Sounding Voyage of H.M.S. 'Hydra,'" already referred to.

5. Every one of the numerous deep Soundings obtained in this Expedition was taken, not only under the superintendence, but actually by the hands, of Capt. Calver himself; of whose skill in the conduct of this operation (which often requires great nicety in the management of the vessel, so as to secure a good up-and-down direction of the line) it is enough to say that it is worthy of the distinguished Service to which he belongs, and to his high position in it. Not a single fathom of line has been lost, and not a single instrument has suffered damage, throughout the whole Expedition.

6. The Dredges supplied to the 'Porcupine' by the Admiralty were constructed upon the model of those which were found to work best in the 'Lightning' Expedition. The experience of the First Cruise, however, in which the dredging was carried down to more than twice the depth attained last year, led Capt. Calver to have a still heavier dredge constructed at Belfast, upon a somewhat different pattern; and it was with this that the very deep Dredgings of the Second cruise were executed, by which the condition of the sea-bottom was successfully investigated at a depth of 2435 fathoms (§§ 45–50)*. An ample supply of strong Dredge-rope was provided; and a very simple and convenient arrangement was devised by Capt. Calver for hanging this in coils upon pins attached to the inner side of the quarter-deck bulwarks (§ 46), so that the *three nautical* miles of line required for the deepest Dredging could be thus disposed without at all encumbering the deck, and in a manner which enabled it to be most conveniently handled both in paying-out and reeling-in, with the additional advantage of keeping it remarkably free from "kinks."

7. An important addition to the Dredging-apparatus, which was devised by Capt. Calver before the commencement of the Third cruise, will be described in its proper place (§ 63). The result of its employment was so extraordinary, that no deep dredging can hereafter be accounted of any value in which it has not been used; and it is only now to be regretted that the idea had not presented itself earlier, so as to have been carried out in the First and Second Cruises.

8. The whole of this equipment would have been ineffective if a suitable Donkey-engine had not been supplied for working it. The experience of the 'Lightning' had shown that a single-cylinder engine is not adapted for this purpose, being liable to stop at either end of its stroke when a heavy strain is put on the drum, and then moving onwards with a jerk, so as to throw on the line a tension which may very probably cause it to part. It was therefore urged upon the Authorities at Woolwich that a double-cylinder engine should be supplied to the 'Porcupine'; and a 'donkey' on this plan was accordingly fixed, which proved most efficient. Nothing could exceed the steadiness of its working, or the facility with which its speed and power could be regulated in accordance with the purposes to

* This is nearly equal to the height of Mont Blanc; and exceeds by more than 500 fathoms the depth from which the Atlantic Cable was brought to the surface.

which it was applied. With the drum ordinarily used it brought up on one occasion, from a depth of 767 fathoms, just *half a ton* of Atlantic mud, in a Dredge which, with its appurtenances, weighed 8 cwt.,—making 18 cwt. in the whole. This was not the limit of its capability; for by the substitution of a smaller drum a still greater power could be obtained,—of course at the sacrifice of speed; and it was by this means that the heaviest Dredge, containing $1\frac{1}{2}$ cwt. of Atlantic mud, was drawn up, by a rope of more than three nautical miles in length, from a depth of 2435 fathoms (§§ 45–50).

9. The working of the Dredge was superintended throughout by Capt. Calver, whose trained ability very early gave him so complete a mastery over the operation, that he found no difficulty in carrying it down to depths at which this kind of exploration would have been previously deemed out of the question. It is impossible for us to speak too highly of the skill he displayed, or too warmly of the sympathy he showed in our work. The placing the Dredge on a bottom nearly three miles from the surface, the working it while there, and the subsequent hauling of it in, with its precious sample of the Life of the Ocean-bed at that vast depth (all executed without the smallest failure, or even such a "hitch" as might have caused the loss of an entire day's work), is an achievement of which our Commander might well be proud, if pride were in his nature. That only one Dredge was lost during the whole Expedition affords ample proof alike of the excellence of his arrangements and of the unwearying assiduity with which they were carried into effective operation. We would here add that the other Officers of the 'Porcupine,' viz. Staff-Commander Inskipp, Mr. Davidson, and Lieut. Browning, most heartily and zealously seconded their Commander, in promoting alike the scientific objects of the Expedition and the welfare and comfort of all who were engaged in carrying them out.

10. With regard to the equipment of the Ship, it only remains to be added that the Chart Room was assigned for the Scientific work of the Expedition; and that the accommodation it afforded (though not all that could be desired) enabled Chemical Analyses and Microscopic observations to be carried on at the same time.

11. The provision of the Apparatus needed for the Physical and Chemical enquiries, which formed a special object of this Expedition, having been placed by the Council of the Royal Society (Minutes for Feb. 18) under the direction of a Committee "consisting of gentlemen practically conversant with the construction and working of such instruments," every arrangement was made which was considered expedient by the very eminent Authorities of which that Committee was composed. The general conclusions at which they arrived are embodied in the Report (p. 401) which they presented to the Council (Minutes of June 17th); but it seems desirable here to record in somewhat greater detail the nature

of the preliminary enquiries made, and the arrangements actually adopted.

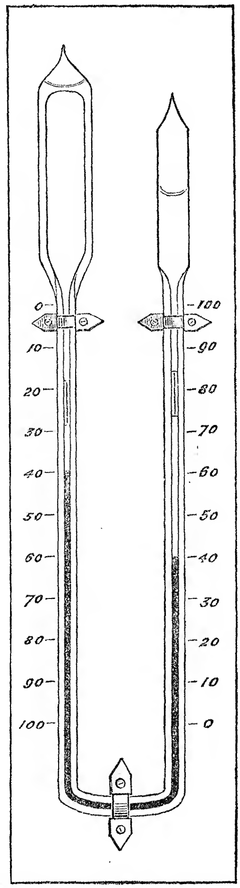
12. It had been remarked in the Report of the "Lightning Expedition" (Proceedings of the Royal Society, Dec. 17, 1868, p. 185) that while the existence of a *minimum* Temperature (probably that of the *bottom*) at least as low as 32° (0° Cent.), over a considerable area of which the depth was between 500 and 600 fathoms, had been conclusively established, the actual *minimum* might probably have been from 2° to 4° *below* that recorded by the Thermometers employed, the pressure of 100 atmospheres, to which their bulbs were subjected at a depth of about 535 fathoms*, being very likely to alter the capacity of the bulbs to that extent. "In any renewal of the enquiry," it was added, "it will be of course desirable that the Thermometric apparatus used should be specially protected from this source of error."

13. So soon, therefore, as there was reason to believe that the application of the Council of the Royal Society for such renewal would be acceded to by H.M. Government, steps were taken to determine the precise amount of this error, and to devise the best means of preventing it. After consultation between the Hydrographer, Dr. Carpenter, and Mr. Casella (the maker of Meteorological Instruments to the Admiralty), it was determined that an apparatus should be constructed on the principle of the Bramah Press; in which Thermometers immersed in water should be submitted to hydraulic pressure, which could be gradually raised till it reached *three tons on the square inch*, its amount being indicated by a pressure-gauge as the experiment proceeded. Mr. Casella further undertook to construct Thermometers with bulbs of extra thickness, in order that it might be ascertained whether the error arising from external pressure (if such should be proved to exist) could be kept in check by this simple expedient. The question was at the same time made the subject of consideration by a Committee appointed by the Council of the Royal Society, as set forth in the Minutes already cited (p. 402, 403); and it was determined that trial should be given to a plan proposed by Dr. W. A. Miller, which consists in the enclosure of the bulb of the Six's Thermometer (the form of Self-registering Thermometer that had been found by experience best adapted to Deep-sea Soundings) in a second or outer bulb, sealed around the neck of the stem,—the space between the inner and outer bulbs being nearly filled with alcohol, and the greater part of the air being displaced from the small unfilled space, by boiling the spirit before the outer bulb is sealed. In this manner the inner bulb is protected from the influence of variations in external pressure upon the outer, the only effect of which is to alter the capacity of the unfilled space; whilst changes of temperature in the medium surrounding the outer bulb are speedily transmitted to the fluid contained within the inner, by convection through the thin stratum

* The pressure of a column of Sea-water of 100 fathoms depth is 280 lbs. upon the square inch, or *one ton* for every 800 fathoms.

of alcohol interposed between the two*. Several Thermometers were constructed upon this plan by Mr. Casella; and these were tested in the pressure-apparatus, together with various instruments of the ordinary construction, as well as with instruments constructed by Mr. Casella with bulbs of extra thickness. A preliminary trial having indicated (1) that the effect of hydraulic pressure upon *ordinary* Thermometers (as shown by the rise of the maximum index) is always very considerable, though varying in amount according to the construction of the instrument, (2) that this effect cannot be prevented by an *increase in the thickness* of the bulb, and (3) that the rise of the *maximum* index in thermometers protected according to Dr. Miller's plan was comparatively trifling,—a series of comparisons between the "protected" and the "unprotected" instruments was very carefully conducted under the direction of Staff-Commander Davis of the Hydrographic Office; who, having had experience in Thermometric Soundings in Sir James C. Ross's Antarctic Expedition, felt specially interested in the determination of this question. In these experiments the difference between the ordinary *unprotected* Thermometers constructed by Mr. Casella for the Admiralty (by which the Temperature-Soundings had been taken in the 'Lightning' Expedition), and *protected* Thermometers constructed on the same pattern in every other respect, was carefully noted at gradually increasing pressures, so as to determine the amount of such difference at depths respectively corresponding to these pressures. The question whether the small elevation of the *maximum* index observed in the *protected* Thermometers is fairly attributable to an actual increment in the temperature of the water in which they are immersed, consequent upon the compression to which it is subjected during the experiment, was carefully considered by Dr. Miller (Proceedings, *loc. cit.*), who satisfied himself,

Fig. 2.



* See Dr. Miller's "Note upon a Self-registering Thermometer adapted to Deep-sea Soundings," in Proceedings of Royal Society, June 17, 1869, p. 482. The same principle had been previously applied in Thermometers constructed under the direction of Admiral Fitzroy, the space between the two bulbs, however, being occupied by mercury instead of spirit. But owing to some imperfection in the construction of these instruments, their performance was not satisfactory, and they were found very liable to fracture.

by experiments devised for the purpose, that this is the true account of it, and that the inner bulb of these Thermometers is not altered in capacity in any appreciable degree by a pressure reaching to *three tons* on the square inch*. This pressure was found to send up the maximum index of the best *unprotected* Thermometers made upon the Admiralty pattern as much as 10°; whilst a pressure of $2\frac{1}{2}$ tons on the square inch sent up the index of an ordinary Phillips's maximum mercurial thermometer no less than 117°·5.

14. A considerable number of Thermometers by different makers, including six protected according to Dr. Miller's plan (all of them previously tested in the Pressure-apparatus), were supplied to the 'Porcupine' by the Meteorological Department; and during its earlier Cruises numerous comparative observations were made at different depths, with the view of determining the differences between the *protected* and various forms of *unprotected* Thermometers at gradationally increasing depths,—such differences being here of course due to *pressure only*. The records of these observations, having been transmitted to the Admiralty, were carefully reduced to curves by Capt. Davis, and compared with their differences at corresponding pressures in the Pressure-apparatus; with the result of showing (when due allowance was made for the small increment of Temperature in the experiments) such a close conformity, that it became obvious that the protected Miller-Casella thermometers might be thoroughly relied on for indicating the true temperature within 1° Fahr. under any pressure not exceeding that to which they had been tested,—this being equivalent to that of a column of Sea-water 2400 fathoms (4389 mètres) deep. This happens to be almost exactly that of the deepest Sounding taken in the 'Porcupine' Expedition, which was 2435 fathoms (4453 mètres).

15. The thorough reliableness of this instrument having been thus demonstrated, it was considered unnecessary to carry the *comparative* observations further; and in the last Cruise two *protected* Thermometers were alone employed. The excellence of these instruments may be inferred from the fact that they never differed more than a few tenths of a degree (Fahr.)†, and that after having travelled vertically downwards and upwards with the Sounding-apparatus to a total amount of nearly a hundred miles (one of the Soundings having been taken at a depth of nearly three miles, and

* [The results of a more elaborate series of investigations subsequently carried on by Staff-Commander Davis, which were communicated to the Royal Society, May 19, 1870, lead him to believe that the small elevation above alluded to is *not entirely* accounted for by increment of Temperature, and that it consequently indicates that *some* influence is still exerted on the inner bulb by Pressure on the outer. The elevation thus produced, however, does not in any case amount to 1° (Fahr.); and the error can be reduced to a scale, by the application of which it can be easily corrected.]

† These small differences are probably due to slight differences in the rate at which the instruments took the temperature of the water around; in which case the *lower* reading would be the most correct.—Before leaving Belfast on the Third Cruise, Prof. Wyville Thomson tested the condition of these Thermometers by immersing them in ice; and they both recorded exactly 32°.

several others at a depth of above two miles), they have been found to be in as good order as when they were first sent out by Mr. Casella. While this most satisfactory result is partly due to the careful handling of the apparatus by Capt. Calver, it is mainly attributable on the one hand to the excellence of the principle on which the Thermometers are constructed, and on the other to the admirable workmanship of Mr. Casella; for the records of previous Temperature-Soundings show that the fracture of the bulbs of unprotected Thermometers at great depths was a very common occurrence, whilst the record of observations made in the 'Lightning' Expedition* shows that the indications of Thermometers of less perfect construction often show a considerable discrepancy.

16. In concluding this account of the behaviour of the protected Miller-Casella Thermometers under the most trying conditions, it may be added that wherever the localities of the Temperature-Soundings taken with these instruments during the Third cruise of the 'Porcupine' were the same (or nearly so) with those of the Temperature-Soundings taken in the 'Lightning' Expedition, *their correspondence proved to be very close,* when the proper correction for the depths at which they were taken was applied to the latter (§ 95). Thus the *differences* of temperature between the Warm and the Cold Areas indicated by those observations† remained the same, although the Temperatures *recorded* by the "unprotected" Thermometers required to be reduced by from 2° to 3° to show the *actual* temperatures,—a recorded temperature of 46° at 650 fathoms in the Warm Area indicating a real temperature of 43°, while a recorded temperature of 32° at 550 fathoms in the Cold Area indicated a real temperature of about 29·8°.

17. As it was considered expedient by the Committee (p. 402) that a trial should be given to Mr. Siemens's apparatus for the determination of deep-sea temperatures, this apparatus (which he terms a Differential Thermometer) was fitted on board the 'Porcupine,' and provided with 1000 fathoms of a small cable about the size of the ordinary Sounding-line, which contained the two insulated wires necessary for the establishment of the two circuits to be brought into comparison. The indications of this instrument depend upon the equalization of two currents transmitted through resistance-coils of fine platinum wire; one of these coils being sent down at the end of the sounding-cable, whilst the other is immersed in a vessel on deck, the water in which can be gradually lowered in temperature by the addition of ice or the use of a freezing-mixture. When the equalization of the currents is shown by the galvanometer, the temperature of the water in the vessel on deck (indicated by an ordinary thermometer) will represent that of the stratum of the sea beneath, in which the resistance-coil is immersed at the time.—Nothing can be more perfect than the working of this apparatus when the Galvanometer rests on a fixed plane surface; and its accuracy and delicacy were satisfactorily proved by experiments carried on not

* Proceedings of the Royal Society, Dec. 17, 1868, p. 172, *notes.*

† Ibid. p. 188.

merely on shore, but also on board the 'Porcupine' when lying in dock or harbour. But it could not be worked with the Galvanometer supplied when there was the least roll of the vessel; for it was then found impossible to make the *zero* observations requisite to indicate equilibrium, though Mr. W. L. Carpenter (who had charge of the apparatus, p. 403) tried every expedient that circumstances admitted. It is obvious, therefore, that this instrument can only be made use of on board ship when the Galvanometer is so suspended as not to participate in the rolling or pitching of the vessel; and it is to be hoped that Mr. Siemens, with his well-known ingenuity, may be able to devise the means of accomplishing this.

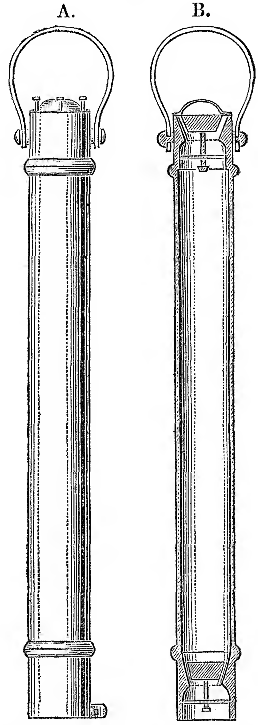
18. It may be well here to mention that as it was found impracticable to employ Mr. Siemens's Differential Thermometer for the determination of the question whether the *minimum* temperature registered by the Thermometers is the actual *bottom* temperature, or is the temperature of some intermediate stratum, this was effected by taking *series* of Temperature Soundings with Thermometers sent down to successively increasing depths in the same locality. Such series were obtained in each of the Cruises; with the result, as will be shown hereafter (§94 *et seq.*), of not merely confirming the conclusion advanced in the 'Lightning' Report (p. 189) that the minimum temperature *is* that of the bottom, but of affording a set of most important data for a general doctrine of the interchange between Equatorial and Polar waters in the great Oceanic basins.

19. The next subject considered by the Scientific Committee was the feasibility of constructing a vessel which should fill itself with Water, either at the bottom or at any intermediate depth, as might be required; and which should bring such water to the surface without the loss of any of the Gases dissolved in it. This might be easily accomplished, were it not for (1) the expansion which water taken under great pressure undergoes when that pressure is removed, the force of which would be sufficient to burst the strongest vessel that could be made; and (2) the expansile force of the gases dissolved in it under great pressure, which would exert itself in the same direction. Various plans were suggested for meeting this difficulty; but it was considered that as time would not permit of the preparation of any but very easily constructed apparatus, it would be better on the present occasion to adopt a form of Water-Bottle suggested by the Hydrographer on the basis of the cylindrical copper cases used for the protection of deep sea thermometers, these having been found to bring up specimens of water whose turbid condition left no doubt that it had come from the stratum immediately covering the soft ocean-bottom. The Water-Bottle constructed on the Hydrographer's plan is a simple strong cylinder of brass, 26 inches long, and 2·3 inch in interior diameter, holding about 60 oz. of water. In the disk which closes it in at each end there is a circular aperture, into which a conical valve is accurately fitted. While this bottle is descending through the water with the Sounding-Apparatus, the valves readily yield to the upward pressure, and

a continuous current streams through it; but so soon as the descent is checked, either by the arrival of the apparatus at the bottom, or by a stop put on the line from above, the valves fall into their places, and thus enclose the water that may fill the bottle at the moment. The ex-

Fig. 3.

A. B.



Water-Bottle as seen at A externally, and at B in section; drawn to a scale of *one-eighth* the actual size.

pansion of this water and of its dissolved gases, as the bottle is brought to the surface, causes a pressure from within, which lifts the upper valve so as to permit the escape of whatever part of the contents of the bottle may be in excess of its capacity. The interior of the bottle was coated with varnish, to prevent the chemical action of the sea-water upon it.—The working of this very simple apparatus was found to be entirely satisfactory. Abundant evidence was obtained that, when it descended to the bottom, it brought up bottom-water: thus, in the area of the "Globigerina-mud," the water was slightly turbid, and deposited after a time a fine sediment (which might be removed by filtration), that proved to consist almost entirely of extremely minute *Globigerinæ*. And hence it may be fairly inferred that when its descent was checked at any intermediate point, the

water brought up in it would be derived from that stratum. Although it can scarcely be supposed that the whole amount of the gases dissolved in the very deep water is retained when the superincumbent pressure is removed, yet it may be inferred, from the slight excess which still usually presented itself, that the very deep water must include a greater proportion of gases than that taken at or near the surface.

20. A number of large glass bottles were provided, for bringing home samples of Sea-water taken in various localities and at different depths; and of these Dr. Frankland kindly undertook to make careful analyses, which should show not merely the proportions of its Saline constituents, but—what has recently come to be a point of most unexpected interest (§ 23)—the amount of Organic matter it may contain. The results of these analyses are stated in Appendix II.

21. But the determination of the nature and proportions of the dissolved Gases could only be effected by immediate analysis; and it was considered by the Committee that it would be expedient to attempt this, notwithstanding the difficulties which might be expected to arise from the motion of the vessel. A method devised by Dr. Miller, as most suitable to the circumstances, was carried into practical operation by Mr. W. L. Carpenter, who succeeded in working this apparatus so efficiently during the First Cruise, and obtained by means of it results of such singular interest, that it was considered desirable that the same system should be followed throughout the Expedition. This work was therefore committed in the Second Cruise to the charge of Mr. Hunter, Assistant to Prof. Andrews of Queen's College, Belfast; and it was carried on during the Third Cruise by Mr. P. Herbert Carpenter, according to the instructions he had received from Mr. Hunter, whom he had accompanied in the Second Cruise.—A general statement of the results obtained, which on the whole accorded well with each other, is included in the present Report (Appendix I.); particulars of the method employed, with details of the analytical results, and a fuller discussion of their *rationale*, will be furnished hereafter by Mr. W. L. Carpenter.

22. The accurate working of a Balance on board a ship at sea being obviously impracticable, the Specific Gravity of every specimen of Deep-sea-water brought up by the bottle was taken by Hydrometers specially constructed to indicate it within the required range to four places of decimals; and this was compared with the Specific Gravity of Surface-water. The determinations obtained by this method, however, of which the results are stated in Appendix I., cannot be regarded as equal in accuracy to those obtained by the Balance; and greater reliance, therefore, is to be placed on the Specific Gravities of the samples analyzed by Dr. Frankland (Appendix II.).

23. Further, tests devised by Dr. Angus Smith to determine the amount of Organic matter (1) in a non-decomposing, and probably therefore an assimilable state, and (2) in a state of decomposition, were frequently applied; with the remarkable result (Appendix I.), which has been since fully con-

firmed by the elaborate analyses of Dr. Frankland (Appendix II.), of indicating the universal presence of a highly Nitrogenous substance, such as may well be supposed to afford a direct supply of nutritive material to the Rhizopodic Fauna (*Sponges* and *Foraminifera*, with *Bathybius*?) of the Ocean-bottom, as was first suggested by Prof. Wyville Thomson in his Memoir on *Holtenia**.

24. For the management of the Dredging-operations two Assistants were appointed on the recommendation of Mr. Gwyn Jeffreys, under whom both of them had previously worked: Mr. Laughrin of Polperro, an old Coastguard-man, and an Associate of the Linnean Society, for dredging and sifting; and Mr. B. S. Dodd for picking out, cleaning, and storing the specimens collected. Both did their respective shares of the work carefully and zealously.

25. The Sieves were constructed under the direction of Mr. Jeffreys. These were five in number, and were "nested" or fitted one within another, with a strong handle of galvanized iron affixed to the bottom sieve on each side; so that the dredged material might pass through all the sieves at the same time, as they were worked in a large tub of sea-water on the deck. Their frames were of oak; and their lining was of copper wove-wire, the mesh of the top sieve being 2 holes to an inch, that of the next 4 holes, and of the succeeding sieves 8, 16, and 32. Each sieve was furnished with a beading round the inside rim, to prevent specimens remaining under the edges when the sieves were washed after each dredging; the risk of intermixture of specimens obtained from different dredgings was thus avoided.

26. Two other kinds of Sieve were also found useful.—One was spherical, with a lid fastened inside by bolts; its frame consisted of a strong network of copper ribs, which was lined with very fine wire-gauze of the same metal, and it had a ring through which a line would pass. Its use was to sift and wash away in the sea the impalpable mud got in large quantities at great depths; so as to leave only for examination all organisms exceeding in size 1-36th of an inch, this being the diameter of the mesh in the wire-lining. Some of the residuum or strained mud was likewise preserved, after sifting the material in the usual way. This contrivance, which we called the "globe-sieve," saved a great deal of the time and useless labour expended in washing dredged material of that viscid kind through the ordinary sieves in a tub of sea-water, which soon becomes so turbid, that unless the tub is continually emptied and refilled it is extremely difficult (if possible) to detect any specimens.—Another kind of sieve had a similar framework; but the body was semiglobose, with an open funnel-shaped neck. It was fastened to a long pole, and served for catching Pteropods, *Salpæ*, and other animals on the surface of the sea. This went by the name of the "scoop-sieve."

27. An ample supply of spirit, jars, and bottles was provided; and the

* Philosophical Transactions, 1869, p. 801.

most convenient storage-room was assigned for them that the small size of the vessel permitted.

28. The unexpected amount of the Collections made during each Cruise, and especially during the Third, put all these resources to a severe test; and it is satisfactory to be able to state that nothing was found wanting which could not be supplied at the ports at which the 'Porcupine' put in.

29. The work of the Expedition was distributed, according to the plan originally marked out, into Three Cruises: the *first* of which was under the Scientific charge of Mr. Jeffreys, who was accompanied by Mr. W. L. Carpenter; the *second* under the Scientific charge of Prof. Wyville Thomson, who was accompanied by Mr. Hunter; and the *third* under the Scientific charge of Dr. Carpenter, who had the advantage of the companionship of Prof. Wyville Thomson, as well as of his son Mr. P. Herbert Carpenter.—The ground assigned to the First and Second Cruises, however, was somewhat different from that originally proposed (p. 399). For as it was considered that the exploration of the "Porcupine Bank," which lies about 150 miles to the west of Galway, and beyond which the water rapidly deepens to 1500 fathoms, would be likely to afford results of great value, and would present a very suitable locality for ascertaining to what depths Dredging could be successfully carried down, it was arranged that this exploration, with that of the deep channel intervening between the British plateau and "Rockall Bank" should be the work of the First Cruise; and that in the Second Cruise this exploration should be carried on in a northerly and north-westerly direction, so as to be connected with the work which had been assigned to the Third Cruise, viz. the more thorough and extended exploration of the region traversed in the 'Lightning' Expedition.—It will be seen hereafter (§ 40) that it was by a change subsequently made in the direction of the Second Cruise that the most remarkable achievement in the whole Expedition was rendered possible.

NARRATIVE.

First Cruise. (Chart, Plate 4.)

30. The First Cruise of H.M.S. 'Porcupine' commenced on the 18th of May, and ended on the 13th of July. It comprised the Atlantic coasts of Ireland, from the Skelligs to Rockall (a distance of about $6\frac{1}{2}°$ or 450 miles), Loughs Swilly and Foyle on the north coast, and the North Channel on the way to Belfast. The first dredging was made on our way round from Woolwich to Galway, on the 24th of May, about forty miles off Valentia, in 110 fathoms; bottom sandy, with a little mud. The Fauna was mostly Northern; and the following are the more remarkable species then procured:—Mollusca: *Ostrea cochlear, Neæra rostrata, Verticordia abyssicola, Dentalium abyssorum, Aporrhaïs Serre-*

sianus, Buccinum Humphreysianum, Murex imbricatus, Pleurotoma carinata, and *Cavolina trispinosa.*—ECHINODERMATA: *Echinus elegans, Cidaris papillata,* and *Spatangus Raschi.*—ACTINOZOA: *Caryophyllia Smithii,* var. *borealis.* Of these, *Ostrea cochlear, Aporrhaïs Serresianus,* and *Murex imbricatus* are Mediterranean species; and *Trochus granulatus* also imparted somewhat of a Southern character, although that species was afterwards found living in the Shetland district. *Ostrea cochlear* is a small deep-water species of Oyster, and is one of the shells which M. Alphonse Milne-Edwards noticed adhering to the Telegraph-Cable between Sardinia and Algiers, at a depth of about 1100 fathoms (see 'Lightning Report,' p. 182); but it has been found (by Mr. Gwyn Jeffreys) attached to the columns of the Temple of Jupiter Serapis at Pozzuoli near Naples, which are reputed not to have been submerged to any considerable depth. The above results of this dredging will give a fair idea of the Fauna inhabiting the 100-fathom line on the West coast of Ireland.

31. After coaling at Galway we steamed southward, and (the weather being very coarse and unpromising) we dredged in Dingle Bay at a depth of from 30 to 40 fathoms; bottom rocky and muddy. As before, in comparatively shallow water, we had two dredges out, one at the bow and the other at the stern; as had been previously the practice of Mr. Jeffreys in his own yacht, when dredging at from 20 to 200 fathoms' depth. In Dingle Bay the dredges several times caught in rocks or large stones, but were saved by the usual yarn-stops, and by the extraordinary strength of the 2-inch Chatham rope which was used. On one occasion, when the dredge was fast, the vessel, which is nearly 400 tons' burden, was pulled round and swung by the rope, as firmly as if she were at anchor and moored by a chain-cable. Here, again, the Mollusca were mostly Northern:—*Siphonodentalium Lofotense, Chiton Hanleyi, Tectura fulva, Odostomia clavula, Trophon truncatus,* and *Cylichna nitidula* fall within this category; while *Eulima subulata, Trophon muricatus, Pleurotoma attenuata,* and *Philine catena* may be reckoned Southern species. But the most remarkable shell obtained in this dredging was *Montacuta Dawsoni,* a species which had been described and figured by Mr. Jeffreys, from specimens found by Mr. Robert Dawson in the Moray Firth. Of this species specimens were subsequently detected by Mr. Jeffreys in the Royal Museum at Copenhagen, in the collection of Greenland shells made by the late Dr. H. P. C. Möller, as well as in Professor Torell's collection of Spitzbergen shells at Lund. The species had been briefly described and noticed by Dr. Möller in the addenda to his 'Index Molluscorum Grœnlandiæ,' as a "Testa bivalvis;" but he did not give it any other name. The size of the Greenland and Spitzbergen specimens is considerably greater than that of British specimens; thus adding another to the numerous cases of a similar kind which have from time to time been adduced by Mr. Jeffreys as justifying his statement that of those species of Mollusca

which are common to Northern and Southern latitudes, and which inhabit the same bathymetrical zone, the Northern are usually larger than the Southern specimens. It may perhaps be a not unfair inference that the origin of such species is Northern, and that they dwindle and become depauperated in proportion to the distance to which they have migrated or been transported from their ancestral homes.

32. The next week was occupied in sounding and dredging off Valentia and on the way to Galway, at depths varying from 85 to 808 fathoms (Stations 2 to 7). The Fauna throughout was Northern; and several interesting acquisitions were made in all departments of the Invertebrata. Among these may be mentioned:—MOLLUSCA: *Nucula pumila* (Norway), *Leda frigida* (Spitzbergen and Finmark), *Verticordia abyssicola* (Finmark), *Siphonodentalium quinquangulare* (Norway and Mediterranean), and an undescribed species of *Fusus*, allied to *F. Sabini*.—ECHINODERMATA: the remarkable *Brisinga endecacnemos*, hitherto only known as a Northern form.—ACTINOZOA: *Flabellum laciniatum*, Edw. and J. Haime = *Ulocyathus arcticus*, Sars (Norway and Shetland, as well as a Sicilian fossil), of which rare and delicate coral unusually perfect specimens were obtained. That fine Shetland Sponge *Phakellia ventilabrum* was also met with thus far south, in 90 fathoms. Many of the most marked types of the deep-water CRUSTACEA of the Shetland sea were here dredged; while in company with these were *Gonoplax rhomboïdes*, Fab., a well-known Mediterranean species, an undescribed and very fine *Ebalia*, a new species of the Mediterranean genus *Ethusa*, together with numerous *Mysidea*, *Cumacea*, and *Amphipoda* new to our Fauna. *Cyprinididæ* also were abundant on this ground. The 808 fathoms' dredging was then a novelty, being (as we believed) the greatest depth ever explored in that way. The length of rope paid out was 1110 fathoms, and the time occupied in hauling in was fifty-five minutes. The same proportionate time was observed in other dredgings during this cruise, viz. five minutes for every 100 fathoms of rope. The dredge contained about two hundredweight of soft and sticky mud, in appearance resembling "China clay." The animals brought up on this occasion were quite lively. More than one specimen was examined of a small Gastropod (described and figured by Mr. Jeffreys as *Lacuna tenella*), which had very conspicuous eyes. There was also a young and active specimen of the large Norwegian Crab, *Geryon tridens*, Kröyer, which is very rare in the Scandinavian seas, and was the only North European Brachyuran which had not as yet been found in British waters. —We had here, for the first time, an opportunity of comparing the temperatures indicated by Dr. Miller's "protected" Thermometers, and those of the ordinary construction, at a considerable depth. The *minimum* recorded by one of the former was 41°·4, whilst that recorded by one of the best ordinary thermometers was 45°·2. As this difference of 3°·8 was almost exactly what the results of the experiments previously made had indicated as the effect of a pressure amounting to *one ton* on the square inch

(the pressure of a column of sea-water at 800 fathoms' depth), this close coincidence gave us a feeling of great confidence in the practical working of the "protected" instrument.

33. We next applied ourselves to the examination of the sea-bed between Galway and the Porcupine Bank, as well as beyond the Bank, at depths ranging from 85 to 1230 fathoms (Stations 10 to 17). All the Mollusca were Northern, except *Aporrhaïs Serresianus*; and even that we are now inclined to consider identical with *A. Macandreæ*, which inhabits the coasts of Norway and Shetland, the latter appearing to be a dwarf variety or form. The more remarkable species were, among MOLLUSCA, *Limopsis aurita* (a well-known tertiary fossil), *Arca glacialis, Verticordia abyssicola, Dentalium abyssorum, Trochus cinereus, Fusus despectus, F. Islandicus, F. fenestratus*, and *Columbella haliæeti* (a tertiary fossil); among ECHINODERMATA, *Cidaris papillata* and *Echinus Norvegicus*; and the fine branching Coral *Lophohelia prolifera*. In the deepest dredging made in this part of the cruise (Station 17, 1230 fathoms), in which the *minimum* temperature (shown by subsequent inquiry to be that of the bottom) was 37°·8, there occurred several new species and two new genera of the *Arca* family, *Trochus minutissimus* of Mighels (a North-American species) having two conspicuous eyes, a species of *Ampelisca* (Crustacean) with the usual number of four eyes, comparatively gigantic *Foraminifera*, and siliceous *Polycystina*. The FORAMINIFERA obtained in these and previous dredgings in deep water were of great interest. A large proportion of them belonged to the *Arenaceous* group, in which the calcareous shell is replaced by a "test" formed of agglutinated sand-grains; and of this group a large number of new types presented themselves, many of them very remarkable both for size and complexity of structure. The *Miliolines*, as in the 'Lightning' dredgings in the Warm area, were of exceedingly large size; and the *Cristellarians* were both large and varied in form, their axis of growth presenting every gradation from the rectilineal to the spiral. An enormous Fish (*Mola nasus*), which is not uncommon on the coasts of Upper Norway, was slowly swimming or floating on the surface of the sea; but we did not succeed in capturing it, for want of a harpoon.

34. We then put into Killibegs, Co. Donegal, and coaled there for our trip to Rockall, which is an isolated and conical rock, standing out of the Atlantic in Lat. 57° 35′, and Long. 13° 41′, at least 200 miles from the nearest land. In anticipation of this trip requiring a clear fortnight, coals were stacked on the deck, in addition to the usual stowage in the bunkers, so as to provide a sufficient supply. Some delay was caused by the non-arrival of a proper galvanometer to work Mr. Siemens's electro-thermometric apparatus, which we were anxious again to try.—We left Donegal Bay on the 27th of June, and returned to the mainland on the 9th of July, after dredging during seven days at depths exceeding 1200 fathoms, and on four other days at less depths. The greatest depth

reached was 1476 fathoms (Station 21). In this last-mentioned dredging we got several living *Mollusca* and other animals, a stalk-eyed *Crustacean* with two prominent and unusually large eyes, and a *Holothurian* of a lilac colour. The bottom at the greater depths consisted of a fine clayey mud, which varied in colour (in some cases being brownish, in others yellow, cream-colour, or drab, and occasionally greyish), and invariably having a greater or less admixture of pebbles, gravel, and sand. The upper layer formed a flocculent mass, which appeared to be animal matter in a state of partial decomposition. This was in all probability derived from the countless multitude of *Salpæ*, oceanic *Hydrozoa*, *Pteropods*, and other gelatinous animals, which literally covered the surface of the sea and filled our towing-net directly it was dipped overboard, and of which the remains must fall to the bottom after death. Such organisms doubtless afford a vast store of nutriment to the inhabitants of the deep.

35. Dredging in such deep water is not accomplished without difficulty. The dredge must be unusually heavy, to overcome the resistance to its sinking occasioned by the friction of the immense length of dredge-line paid out; and when it reaches the bottom, it sinks by its own weight into the mud, like an anchor. This would give only the same result as the cup-lead or any sounding-machine, but on a larger scale; and it would tell us very little about the Fauna. Further, if by the drift-way of the vessel, or by a few turns of the engine now and then, we are enabled to scrape the surface of the sea-bed, the dredge gets choked up with the flocculent mass above described. The fertile ingenuity of our experienced and excellent Commander devised a method which was a great improvement in deep-sea dredging, and which enabled us to obtain at least a sample of the substratum. This consisted in attaching to the rope two iron weights, each of 100 lbs., at a distance of 300 or 400 fathoms from the dredge (when the depth exceeded 1200 fathoms), so as to dredge from the weights instead of from the ship; the angle thus made caused the blade of the dredge to lie in its proper position. This method, in fact, reduced the working depth, by the distance of these weights from the vessel, to the easy and manageable limit of 300 or 400 fathoms. Another contrivance was to fasten the bag to the dredge in such a way that when it was hauled in, it could be unlaced, emptied, and afterwards washed quite clean. By this mode we were assured that the specimens really came from the place where each dredging was made. We tried on this and other occasions a contrivance devised by Mr. Easton, the eminent engineer, consisting of gutta-percha valves closing inwards in a wedge-like form, which were fitted to the mouth of the dredge. The object was to retain the contents of the dredge while it was being hauled in; as we had found by frequent and disappointing experience that a large portion of the contents generally escape through the mouth during this part of the dredging operation. This contrivance, though theoretically admirable, was found not to answer in practice, because the mouth of the dredge was so closed by the valves that

it had no contents to be retained. The principle, however, seems so good, that we should hope it may be more successfully applied.

36. The very deep dredgings in this trip yielded an abundance of novel and most interesting results in every division of Invertebrata. Among the MOLLUSCA were valves of an imperforate Brachiopod, with a septum in the lower valve, which we propose to name *Atretia gnomon.* Some shells were of a considerable size; and the fry of *Isocardia cor* (*Kelliella abyssicola,* Sars) were not uncommon. Among the CRUSTACEA there were new species of *Cumacea*; a beautiful *Amphipod* of a bright red colour, with feathery processes of a golden colour at the tail; with a considerable variety of *Isopoda, Phyllopoda,* and *Ostracoda,* among them several forms apparently new. There was also a magnificent *Annelid,* of a purplish hue, with purplish-brown spots on the line of segmentation. Two or three young specimens were here obtained, at a depth of 1215 fathoms (Station 28), of a most interesting *Clypeastroid,* of which a mature example was afterwards dredged in the Third Cruise (§ 77). These were at once recognized as belonging to an entirely new type; but since our return we find that a form, generically if not specifically the same, had been obtained by Count Pourtales during his last dredgings in the Gulf of Mexico, and had been described by Prof. Alex. Agassiz under the name *Pourtalesia miranda.* This type is of extraordinary interest from its being the living representative of a very singular little group of the *Ananchytidæ* (including the genus *Infulaster,* D'Orb., to which it seems most closely allied), which are specially characteristic of the newer Chalk. In the 1443 fathoms' dredging (Station 20) a *Holothurian* was obtained 5 inches long and $2\frac{1}{4}$ inches in circumference. Several very fine *Corals* were obtained during the Rockall trip; among them magnificent examples of *Lophohelia prolifera* and *Caryophyllia Smithii.* The *Foraminifera,* as before, were remarkable for their size, the same types being generally predominant. But specimens were here obtained for the first time of a peculiarly interesting *Orbitolite,* a type not hitherto discovered further north than the Mediterranean, and there attaining a comparatively small size. Perfect specimens of this *Orbitolite* must have a diameter of a sixpence; but owing to its extreme tenuity, and to the facility with which the rings separate from each other, no large specimens were obtained unbroken, though it was evident that their fracture had taken place in the process of collection. No greater proof can be adduced of the extreme *stillness* of the bottom at great depths, than is afforded by the extraordinary delicacy of these disks, which are so fragile as to be with difficulty mounted for observation. Their plan of growth corresponds with that of the "simple type" of this genus, all the "chamberlets" being on the same plane; but the form of the chamberlets corresponds with that of the chamberlets of the superficial layers of the "complex type" *. It is a fact of peculiar significance that instead

* See Dr. Carpenter's "Researches on the *Foraminifera,*" Part I., in the Philosophical

of commencing with a "central" and "circumambient" chamber, like ordinary Orbitolites, this type commences with a *spire* of several turns, precisely like that of a young *Cornuspira,* thus showing the fundamental conformity of this *cyclical* type to the *spiral* plan of growth.—The animals, especially Mollusca, were by no means lively when brought on board and examined; perhaps this was owing to the great change of temperature (sometimes as much as 20°) between that of the sea-bed and that of the atmosphere.

37. A very elaborate Series of Temperature-soundings was made in the deepest parts of the sea traversed between the N.W. of Ireland and Rockall Bank, so as to enable us to determine the rate of diminution of temperature with increase of depth (see Table, p. 465). Thus at Station 19, at which the depth was 1360 fathoms, the temperatures were taken at 250, 500, 750, 1000, and 1360 fathoms, and showed a progressive though by no means uniform descent to the *minimum* recorded, which was 37°·4; the most rapid change was between 500 and 750 fathoms. A similar Series, taken at Station 20, where the depth was 1443 fathoms and the bottom-temperature 37°·0, and a third taken at Station 21, where the depth was 1476 fathoms, and the bottom-temperature 36°·9, showed a very close accordance with each other and with the preceding. In another Series taken at Station 22 in 1263 fathoms, a careful comparison was made between the temperatures recorded by *two* "protected" thermometers and *six* ordinary thermometers; and the average error of these, which was very nearly 6° at the greatest depth, corresponded very closely with that indicated by the previous experiments at pressures answering to the several depths at which the observations were made.—The curious observation was made at Station 23, very near the Rockall Bank, that whilst the *minimum* indicated was 43°·4 at a depth of 630 fathoms, the *maximum* index of both thermometers had risen to 74°·8, or more than 17° above the surface-temperature. As in no other instance had any temperature been indicated higher than that of the surface, it seemed clear that a warm submarine spring must discharge itself in this locality. Circumstances prevented us, however, from ascertaining any further particulars in regard to it.

38. While we lay-to within a quarter of a mile from Rockall on the evening of Saturday the 3rd of July, fishing-parties were formed, and continued their sport until midnight. The rock was inhabited by a multitude of sea-fowl; and a large gannet perched on the highest pinnacle, looking like a sentinel or the president of the feathered republic.

39. At a distance of from 130 to 140 miles from the nearest part of the Irish coast we observed quantities of floating Seaweed (mostly *Fucus serratus*), and the feathers of sea-fowl covered with *Lepas fascicularis* and occasionally *L. sulcata*; and on the seaweed were also two kinds of sessile-

Transactions for 1855, p. 193 *et seq.*; and his "Introduction to the Study of the *Foraminifera,*" p. 106 *et seq.*

eyed Crustaceans. The wind having been previously easterly, it is difficult to say what share the wind or tide had in the drift; but it could scarcely have been caused by any circulation from the equator. The Fauna nowhere showed the least trace of that wonderful and apparently restricted current known as the Gulf-stream. The beautiful Pteropod *Clio pyramidata* flitted about in considerable numbers; a delicate Cuttlefish (*Leachia ellipsoptera*), which is supposed to prey on *Salpæ*, was caught in the scoop-sieve, as well as several specimens of a small and very slender *Syngnathus* or pipefish. On our homeward passage we experienced severe weather, in which our vessel sustained some injury from the heavy cross seas which struck her. After putting into Killibegs we dredged in Lough Swilly, Lough Foyle, and the North Channel on the way to Belfast, where we arrived on the 13th of July.

Second Cruise. (Chart, Plate 5.)

40. As already stated, it was the original intention to devote the Second Cruise to the exploration of an area to the west of the outer Hebrides, between Rockall and the south-western limit of last year's work in the 'Lightning.' During the First Cruise, however, dredging had been carried down successfully to a depth of nearly 1500 fathoms; and the result so far realized our anticipations, and confirmed the experience of last year. The conditions (to that great depth at all events) were consistent with the life of all the types of Marine Invertebrata; though undoubtedly in very deep water the number of species procured of the higher groups was greatly reduced, and in many cases the individuals appeared to be dwarfed. From these observations (which thoroughly corroborated those of Dr. Wallich and others, about which there had been some difference of opinion on account of the imperfection of the appliances at the command of the observers), we concluded that probably in no part of the ocean were the conditions so altered by Depth as to preclude the existence of Animal Life,—that Life had no Bathymetrical limit. Still we could not consider the question thoroughly settled; and when, upon consultation with Captain Calver, we found him perfectly ready to attempt any depth, and from his previous experience sanguine of success, we determined to apply to the Hydrographer to sanction an attempt to dredge in the deepest soundings within our reach, viz. 2500 fathoms indicated on the chart 250 miles west of Ushant. The deepest reliable soundings do not go much beyond 3000 fathoms; and we felt that if we could establish the existence of Life, and if we could determine the conditions with accuracy down to 2500 fathoms, the general question would be virtually solved for all depths of the ocean, and any further investigation of its deeper abysses would be mere matter of curiosity and of detail. The Hydrographer cordially acquiesced in this change of plan; and on the 17th of July the 'Porcupine' left Belfast under the scientific direction of Professor Wyville Thomson; Mr. Hunter,

F.C.S., Chemical Assistant in Queens College, Belfast, taking charge of the examination and analysis of the sea-water.

41. The weather was very settled. On the Sunday, as we steamed down the Irish Channel, there was nearly a dead calm, a slight mist hanging over the water, and giving some very beautiful effects of coast scenery. On the evening of Sunday the 18th we anchored for the night off Ballycottin, a pretty little port about fifteen miles from Queenstown, and dropped round to Queenstown on Monday morning, where we anchored off Haulbowline Island at 7 A.M. At Queenstown Mr. P. Herbert Carpenter joined Mr. Hunter in the laboratory, to practise under his direction the gas-analysis, which it had been arranged that he should undertake during the Third Cruise. Monday the 18th was employed in coaling and procuring in Cork some things which were required for the chemical department; and at 7 P.M. we cast off from the wharf at Haulbowline and proceeded on our voyage.

42. During Monday night we steamed in a south-westerly direction across the mouth of the Channel. On Tuesday we dredged in 74 and 75 fathoms on the plateau which extends between Cape Clear and Ushant, on a bottom of mud and gravel with dead shells and a few living examples of the generally diffused species of moderate depths. The weather was remarkably fine, the barometer 30·25 in., and the temperature of the air 72°·5.

43. On Wednesday, July 21st, we continued our south-westerly course, the chart indicating during the earlier part of the day that we were still in the shallow water of the plateau of the Channel. At 4.30 A.M. we dredged gravel and dead shells in 95 fathoms, but towards mid-day the lead gave a much greater depth; and in the afternoon, rapidly passing over the edge of the plateau, we dredged in 725 fathoms with a bottom of muddy sand (Station 36). This is about the bathymetrical horizon at which we find the Vitreous Sponges in the northern area; and although the bottom is here very different, much more sandy with but a slight admixture of *Globigerina* ooze, we dredged a tolerably perfect, though dead, specimen of *Aphrocallistes Bocagei,* a vitreous sponge lately described by Dr. E. Perceval Wright from a specimen procured by Professor Barboza du Bocage from the Cape-Verde Islands, and one or two small specimens of *Holtenia Carpenteri.* The muddy sand contained a considerable proportion of gravel and dead shells.

44. On Thursday, July 22nd, the weather was still remarkably fine. The sea was moderate, with a slight swell from the north-west. We sounded in lat. 47° 38′ N., long. 12° 08′ W., in a depth of 2435 fathoms (Station 37). The Sounding-line used on this occasion was medium No. 2, of the best Italian hemp, the No. of threads 18, the weight per 100 fathoms 12 lbs. 8 oz., the circumference 0·8 inch, and the breaking-strain, dry, 1402 lbs., soaked a day, 1211 lbs.; and the 'Hydra' sounding-instrument was weighted with 336 lbs. The weight attached to the sounding-apparatus is of course allowed to descend quite freely without any check, but its velocity is

gradually and uniformly reduced during its descent by the increasing friction of the lengthening line. The uniformity of this retardation gives an infallible test of the success of the sounding, and a certain indication of the moment when the weight reaches the bottom. The latter was, however, valuable only for corroboration, as even at these enormous depths the shock of the arrest of the weight on the bottom, nearly three miles down, was distinctly perceptible to the skilled hand of our Commander. As the scientific value of our results depends upon the certainty of the determination of the depths, we subjoin a Table of the absolute rate of the descent of the weight in this sounding,—probably the deepest hitherto made which is thoroughly reliable, having been taken with the most perfect appliances, and with consummate skill.

Fathoms.	Time.	Interval.	Fathoms.	Time.	Interval.
	h m s	m s		h m s	m s
0	2 44 20		1300	58 5	1 23
100	45 5	45	1400	2 59 37	1 32
200	45 45	40	1500	3 1 9	1 32
300	46 30	45	1600	2 42	1 33
400	47 25	55	1700	4 19	1 37
500	48 15	50	1800	6 6	1 47
600	49 15	1 0	1900	7 53	1 47
700	50 24	1 9	2000	9 40	1 47
800	51 23	59	2100	11 29	1 49
900	52 45	1 22	2200	13 24	1 55
1000	54 0	1 15	2300	15 23	1 59
1100	55 21	1 21	2400	17 15	1 52
1200	56 42	1 21	2435	17 55	40

The whole time occupied in descent was 33 minutes 35 seconds; and in heaving up 2 hours 2 minutes. The cylinder of the sounding-apparatus came up filled with fine grey Atlantic ooze, containing a considerable proportion of fresh shells of *Globigerina*. The two Miller-Casella thermometers, Nos. 100 and 103, attached as usual to the line above the sounding-instrument, registered a minimum temperature of 36°·5 F. (2°·5 C.).

45. A Dredge was sent down at 5.45 P.M.; and as this was the deepest haul, the one which tested our resources most fully, and which seemed to us to prove that dredging could, with sufficient care and skill, be successfully carried out in any known depth in the ocean, we give here the details of the operation and the appliances used.—The dredge was of wrought iron, made on exactly the same plan as the "Naturalists'" dredge introduced by Ball and Forbes. The two scrapers were pitched at a very low angle. The arms were moveable, and about half of each arm next the eye to which the rope was attached was of strong chain: we are by no means sure, however, that this was an advantage. On one side the chain was attached to the arm of the dredge by a stop of five turns of spun yarn, so that in case of the dredge becoming entangled, or wedged by rocks or stones, a strain less than sufficient to break the dredge-rope would break the stop, alter the position of the dredge, and probably enable it

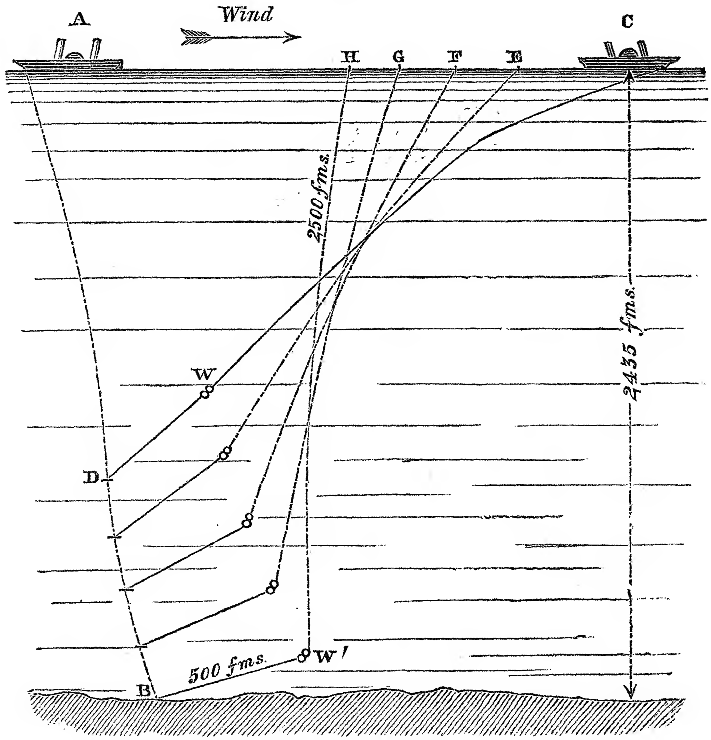
to free itself. The weight of the frame of the dredge was 225 lbs.; the mouth was about 4 feet 6 inches long by 6 inches wide at the throat or narrowest part, at the inner edge of the scrapers. The dredge-bag was double; the outer bag of strong twine netting, the meshes of the net $\frac{3}{4}$ inch in diameter; the inner of "bread-bag," a coarse open canvas. By an ingenious device of Captain Calver, the inner bag was divided into a set of compartments by pieces of plank fitted vertically into it from the mouth nearly to the bottom. This arrangement was intended to prevent the washing out of the contents of the dredge during its long upward journey.

46. The length of the dredge-rope was 3000 fathoms, nearly $3\frac{1}{2}$ statute miles; of this 2000 fathoms were "hawser-laid" $2\frac{1}{2}$ inches, with a breaking strain of $2\frac{1}{4}$ tons. The 1000 fathoms next the dredge were "hawser-laid" 2 inches. There was an admirable arrangement for stowing the rope—an arrangement which made its manipulation singularly easy, notwithstanding its great bulk and weight (about 5500 lbs.). A long row of large iron pins, about 2 feet in length, projected, rising obliquely from the top of the bulwark, along one side of the quarter-deck. Each of these held a coil of from 200 to 300 fathoms, and the rope was coiled continuously along the whole row. While the dredge was going down, the rope was rapidly taken by the men from these pins ("Aunt Sallies" we called them, from their each ending over the deck in a smooth white wooden ball) in succession, beginning with the one nearest the dredging-derrick; and in hauling up, a relay of men carried the rope along from the surging-drum of the donkey-engine, and hung it in coils on the pins in inverse order. A heavy spar formed a powerful derrick projecting over the port bow. A large block was suspended at the end of the derrick by a rope, which was not directly attached to the end of the derrick, but passed through an eye, and was fixed to a "bitt" on the deck. On a bight of this rope, between the "bitt" and the block, was lashed the "accumulator" described above (§ 1). The result of this arrangement was, that when any undue strain came upon the dredge-rope, the strain acted first upon the "accumulator;" and a graduated scale on the derrick, against which the "accumulator" played, gave, in cwts., an approximation, at all events, to the strain upon the rope. In letting go, the rope passed to the block of the derrick directly from the "Aunt Sallies;" in hauling up it passed from the block to the surging-drum of the admirable double-cylinder donkey-engine already mentioned, from which it was taken by the men and coiled on the "Aunt Sallies." Three sinkers were attached to the dredge-rope, one of 1 cwt., and the others of 56 lbs. each, at 500 fathoms from the dredge.

47. The 3000 fathoms of rope were out at 5.55 P.M., the vessel drifting slowly before a moderate breeze (force=4) from the N.W. The accompanying woodcut gives an idea of the various relative positions of the dredge and the vessel, according to the plan of dredging followed by Capt. Calver, which answered admirably.

A represents the position of the vessel when the dredge is let go, and the dotted line A B the line of descent of the dredge, rendered oblique by the tension of the rope. While the dredge is going down, the vessel drifts gradually to leeward; and when the whole (say) 3000 fathoms of rope are out, C, W, and D might represent the relative positions of the vessel, the weight attached 500 fathoms from the dredge, and the dredge itself.

Fig. 4.



The vessel now steams slowly to windward, occupying successively the positions E, F, G, and H. The weight, to which the water offers but little resistance, sinks from W to W', and the dredge and bag move slowly from D to B. The vessel is now allowed to drift back before the wind from H towards C. The tension of the motion of the vessel, instead of acting immediately upon the dredge, now drags forward the weight W', so that the dredging is carried on from the weight, and not directly from the vessel. The dredge is thus quietly pulled along, with its lip scraping the bottom in the attitude which it assumes from the position of the centre of weight of its iron frame and arms. If, on the other hand, the weights were hung close to the dredge, and the dredge were dragged directly from

the vessel, owing to the enormous weight and spring of the rope, the arms would be constantly lifted up, and the lip of the dredge prevented from scraping.—For very deep dredging, this operation of steaming up to windward till the dredge-rope was nearly perpendicular, after drifting for half an hour or so to leeward, was usually repeated three or four times.

48. At 8.50 P.M. we began to haul in, and the "Aunt Sallies" to fill again. The engine delivered the rope steadily at a uniform rate of rather more than a foot per second.—It is worthy of record that, except on one or two occasions, when an enormous load, at one time nearly a ton, came up in the dredge-bag, the donkey-engine maintained the same rate of heaving during the whole summer's work. A few minutes before 1 A.M. the weights appeared; and at one in the morning, $7\frac{1}{4}$ hours after it was cast over, the dredge was safely hauled on deck, having in the interval accomplished a journey of upwards of eight statute miles. The dredge-bag contained $1\frac{1}{2}$ cwt. of the very characteristic pale grey Atlantic ooze. The total weight brought up by the engine was—

2000 fathoms $2\frac{1}{2}$-inch rope	4000 lbs.
1000 fathoms 2-inch rope	1500 lbs.
	5500 lbs.
Weight of rope reduced to one quarter in the water=	1375 lbs.
Dredge and bag	275 lbs.
Ooze brought up	168 lbs.
Weight attached	224 lbs.
	2042

49. The Dredge, with its contents, was reverently laid aside under a tarpauling, and the watchers threw themselves down to rest till daylight. The contents of the dredge had the ordinary character of Atlantic chalk-mud. Since our return it has been analyzed by Mr. Hunter, who finds it to contain (besides an appreciable quantity of Organic matter, the exact proportion of which has not yet been accurately ascertained)—

Silica	23·34
Ferric oxide	5·91
Alumina	5·35
Carbonate of calcium	61·34
Carbonate of magnesium	4·00
Loss	0·06
	100·00

the alkalies having been removed by washing.—The ooze has not yet been subjected to careful Microscopic examination. The dredge appeared to have dipped pretty deep into the soft mud; its contents therefore contained but a small proportion of fresh shells of *Globigerina* and *Orbulina*.

There was an appreciable quantity of diffused amorphous organic matter, which we were inclined to regard as connected, whether as processes, or "mycelium," or germs, with the various shelled and shelless Protozoa.

50. On careful sifting, the ooze was found to contain fresh examples of each of the Invertebrate Subkingdoms. When examined at daylight on the morning of the 23rd, none of these were actually living, but their soft parts were perfectly fresh, and there was ample evidence of their having been living when they entered the dredge. The most remarkable species were:—

MOLLUSCA.—*Dentalium*, sp. n., of large size.
Pecten fenestratus, a Mediterranean species.
Dacrydium vitreum, Arctic, Norwegian, and Mediterranean.
Scrobicularia nitida, Norwegian, British, and Mediterranean.
Neæra obesa, Arctic and Norwegian.

CRUSTACEA.—*Anonyx Hölbollii*, Kröyer (=*A. denticulatus*, Bate), with the secondary appendage of the upper antennæ longer and more slender than in shallow-water specimens.
Ampelisca æquicornis, Bruzelius.
Munna, sp. n.

One or two ANNELIDES and GEPHYREA, which have not yet been determined.

ECHINODERMATA.—*Ophiocten Kröyeri*, Lütken; several well-grown specimens.
Echinocucumis typica, Sars. This seems to be a very widely distributed species; we got it in almost all our deep dredgings, both in the Warm and in the Cold areas.

A remarkable stalked Crinoid, allied to *Rhizocrinus*, but presenting some very marked differences.

POLYZOA.—*Salicornaria*, sp. n.

CŒLENTERATA.—Two fragments of a Hydroid Zoophyte.

PROTOZOA.—Numerous Foraminifera belonging to the groups already indicated (§ 33) as specially characteristic of these abyssal waters; together with *a branching flexible Rhizopod*, having a chitinous cortex studded with Globigerinæ, which encloses a sarcodic medulla of olive-green hue. This singular organism, of which fragments had been detected in other dredgings, here presented itself in great abundance.

One or two small SPONGES, which seem to be referable to a new group.

51. On Friday, July 23, we tried another haul at the same depth; but when the dredge came up at 1.30 P.M. it was found that the rope had fouled and lapped right round the dredge-bag, and that there was nothing

in the dredge. The dredge was sent down again at 3 P.M., and was brought up at 11 P.M., with upwards of 200 cwt. of ooze.—We got from this haul a new species of *Pleurotoma* and one of *Dentalium*, *Scrobicularia nitida*, *Dacrydium vitreum*, *Ophiocantha spinulosa*, and *Ophiocten Kröyeri*, with a few Crustaceans and many Foraminifera.

52. In both of these last deep dredgings the dredge brought up a large number of extremely beautiful *Polycystina*, and some forms apparently intermediate between *Polycystina* and Sponges, which will be described shortly. These organisms did not seem to be brought from the bottom, but appeared to be sifted into the dredge on its way up. They were as numerous adhering to the outside of the dredging-bag, as within it. During the soundings taken near this locality quite a shower of several beautiful species of the *Polycystina* and *Acanthometrina* fell upon the chart-room sky-light from the whole length of the sounding-line while it was being hauled in.

53. Dredging in such deep water was very trying. Each operation occupied seven or eight hours; and during the whole of that time it demanded and received the most anxious attention on the part of the Commander, who stood with his hand on the pulse of the Accumulator, ready at any moment, by a turn of the paddles, to ease any undue strain. The men, stimulated and encouraged by the cordial interest taken by their officers in our operations, worked willingly and well; but the labour of taking upwards of three miles of rope, coming up with a heavy strain from the surging-drum of the engine, and coiling it upon the "Aunt Sallies," was very severe. The rope itself looked frayed and strained, as if it could not be trusted to stand this extraordinary ordeal much longer. The question of the distribution of Life and the condition of the bottom had been solved; and the animals brought up, though of surprising interest, were few in number. On the morning of Saturday the 24th we therefore determined to cease dredging for the present, and to devote the day to an investigation which we regarded as at least equal in importance,—the determination of a series of Temperatures at intervals of 250 fathoms from the bottom to the surface. The following is a Table of the mean results of this series of observations (Station 38). The instruments used were the two Miller-Casella thermometers which were employed in all the temperature-soundings throughout the summer. The depth was 2090 fathoms.

Surface-temperature 64° F.=17°·08 C.

260 fathoms	...... 50·5	„ 10·28,	less than surface ..	13°·5 F.	=	7°·5 C.
500 „	...... 47·8	„ 8·8,	„ 250 fath.	2·7	„	1·5
750 „	...... 41·3	„ 5·17,	„ 500 „	6·5	„	3·6
1000 „	...... 38·3	„ 3·5,	„ 750 „	3·0	„	1·7
1250 „	...... 37·7	„ 3·17,	„ 1000 „	0·6	„	0·3
1500 „	...... 37·2	„ 2·9,	„ 1250 „	0·5	„	0·3
1750 „	...... 36·7	„ 2·61,	„ 1500 „	0·5	„	0·3
2090 „	...... 36·3	„ 2·4,	„ 1750 „	0·4	„	0·2

54. The general result of this series of Soundings is of the highest interest; and although it may be premature to attempt an explanation of the details of the phenomena until all the temperature-observations which have been made in the North Atlantic have been reduced to the Miller-Casella standard and carefully correlated, still certain general conclusions seem self-evident.—The high surface-temperature, reduced by 13½ degrees at 250 fathoms, is undoubtedly due to superheating by the direct heat of the sun. This is shown more clearly by the Table (§ 58), where nearly 7° are seen to be lost between the surface and 30 fathoms, and 4° more between 30 fathoms and 100 fathoms.—From 100 to 500 fathoms the temperature is still high and tolerably uniform, and it falls rapidly between 500 and 1000 fathoms; a reference to the second Table shows that the rapid fall is between 650 and 850 fathoms, during which interval there is a loss of nearly 6°. The second stage of elevated temperature, from 250 to 650 fathoms, seems to be caused by the north-easterly reflux of the great equatorial current. From 1000 fathoms the loss of heat goes on uniformly at the rate of 0°·5 for every 250 fathoms. The most singular feature in this decrease of temperature for the last mile and three quarters is its absolute uniformity, which appears to be inconsistent with the idea of a current, unless it were one of excessive slowness. It appears that the presence of this vast underlying body of comparatively cold water can only be accounted for on the supposition of a general interchange of warm and cold water, according to the doctrine laid down by Dr. Carpenter in the 'Lightning' Report, which will be more fully expounded hereafter (§ 115).

55. We were now steaming slowly back towards the coast of Ireland; and on Monday, July 26, we dredged in depths varying from 557 to 584 fathoms (Stations 39–41) in ooze, with a mixture of sand and dead shells. In these dredgings we got one or two very interesting Alcyonarian zoophytes, and several Ophiuridans, including *Ophiothrix fragilis, Amphiura Ballii,* and *Ophiacantha spinulosa.* Many of the animals were most brilliantly phosphorescent; and we were afterwards even more struck by this phenomenon in our Northern Cruise. In some places nearly everything brought up seemed to emit light, and the mud itself was perfectly full of luminous specks. The Alcyonarians, the Brittle-stars, and some Annelids were the most brilliant. The *Pennatulæ,* the *Virgulariæ,* and the *Gorgoniæ* shone with a lambent white light, so bright that it showed quite distinctly the hour on a watch. The light from *Pavonaria quadrangularis* was pale lilac, like the flame of cyanogen; while that from *Ophiacantha spinulosa* was of a brilliant green, corruscating from the centre of the disk, now along one arm, now along another, and sometimes vividly illuminating the whole outline of the star-fish.

56. The question of the amount and the kind of Light in these abysses was constantly before us. That there *is* light, there can be no doubt. The eyes in many species of all classes were well developed; in some, very

remarkably so. A *Munida*, probably a variety of *Munida Banffii*, somewhat paler in colour than usual, and somewhat slighter in its proportions, which we met with abundantly in our northern dredgings, had remarkably large eyes, very brilliant, transparent, and bronzy, giving the impression of extreme sensitiveness. It is scarcely possible that any appreciable quantity of the Sun's light can penetrate beyond two hundred fathoms at most. The data with regard to the transmission of light through seawater are very scanty; but the rapidity with which light diminishes during the first few fathoms seems to point to its speedy extinction. It seemed to us probable that the abyssal regions might depend for their light solely upon the Phosphorescence of their inhabitants. The only use which the lower animals make of light is to enable them to procure their food; and it is evident that in the night, or under any circumstances in which there is no source of general illumination, it would answer the same purpose of guiding them to their prey, if that prey itself were luminous. Among the Starfishes the young specimens, 10 to 15 millims. from point to point of the rays, appeared to be much more luminous than mature examples of the same species. This is probably part of the great general plan which provides an enormous excess of the young of many species apparently as a supply of food; their wholesale destruction being necessary for the due restriction of the multiplication of the species, while the breeding individuals, on the other hand, are provided with special appliances for escape or defence. It is well known that fishes feed principally at night; and the path of a shoal of herrings may often be traced for miles by the broad band of phosphorescence caused by the glowing and scintillating of the myriads of phosphorescent animals, especially larvæ, with which the sea is crowded, and which supply their food. We can scarcely doubt that the phosphorescence of the inhabitants of the dark abysses of the sea performs, in regard to the great object of the supply of food, the functions performed in the upper world by the light of day.

57. On the 27th we dredged in 862 fathoms (Station 42), the weather being still very fine, and the sea quite smooth. The bottom was ooze with sand and dead shells. Among the Mollusca procured were a new species of *Pleuronectia*, *Leda abyssicola* (Arctic), *Leda Messinensis* (a Sicilian Tertiary fossil), *Dentalium gigas* (sp. n.), *Siphonodentalium* (sp. n.), *Cerithium metula*, *Amaura* (sp. n.), *Columbella Haliæeti*, *Cylichna pyramidata* (Norwegian and Mediterranean), and many dead shells of *Cavolina trispinosa*. These latter were very common in all the northern dredgings, though we never saw a living specimen on the surface.

58. During the afternoon we took a series of intermediate temperatures, at intervals of 50 fathoms, from the bottom at 862 fathoms to the surface. The following Table gives the general results of this series of observations:—

Surface (mean temp. of 100, Miller-Casella 103)	62·8° F.	=	17·22° C.						
10 fathoms	62·1	,,	16·72,	less than surface			0·7° F.	=	0·5° C.
20 ,, ...	59·4	,,	15·22,	,,	10 fath.		2·7	,,	1·5
30 ,, ...	56·0	,,	13·33,	,,	20	,,	3·4	,,	1·9
40 ,, ...	54·4	,,	12·44,	,,	30	,,	1·6	,,	0·9
50 ,, ...	53·2	,,	11·8,	,,	40	,,	1·2	,,	0·64
100 ,, ...	51·1	,,	10·6,	,,	50	,,	2·1	,,	1·2
150 ,, ...	50·9	,,	10·5,	,,	100	,,	0·2	,,	0·1
200 ,, ...	50·5	,,	10·3,	,,	150	,,	0·4	,,	0·2
250 ,, ...	50·2	,,	10·11,	,,	200	,,	0·3	,,	0·2
300 ,, ...	49·6	,,	9·8,	,,	250	,,	0·6	,,	0·3
350 ,, ...	49·1	,,	9·5,	,,	300	,,	0·5	,,	0·3
400 ,, ...	48·5	,,	9·17,	,,	350	,,	0·6	,,	0·3
450 ,, ...	47·6	,,	8·7,	,,	400	,,	0·9	,,	0·5
500 ,, ...	47·4	,,	8·55,	,,	450	,,	0·2	,,	0·15
550 ,, ...	46·4	,,	8·0,	,,	500	,,	1·0	,,	0·55
600 ,, ...	45·5	,,	7·4,	,,	550	,,	0·9	,,	0·5
650 ,, ...	44·3	,,	6·83,	,,	600	,,	1·2	,,	0·6
700 ,, ...	43·6	,,	6·44,	,,	650	,,	0·7	,,	0·4
750 ,, ...	42·5	,,	5·83,	,,	700	,,	1·1	,,	0·6
800 ,, ...	42·0	,,	5·55,	,,	750	,,	0·5	,,	0·3
862 ,, ...	39·7	,,	4·3,	,,	800	,,	2·3	,,	1·25

A Water-Bottle was sent down with the sounding-lead on each occasion; and the specific gravity of the water was carefully taken, the air contained in it analyzed, and the amount of organic matter estimated by Mr. Hunter. Mr. Hunter's results, which are given below, corroborate generally the observations made on the previous cruise by Mr. William L. Carpenter. The Specific Gravity of the water is somewhat higher at the surface than at a depth of 50 fathoms; this is probably due to evaporation, the observation having been made after a course of hot weather. From 50 fathoms downwards it increases slightly but steadily till within 50 fathoms of the bottom, when it again falls a little. The proportion of Carbonic acid in the contained gases increases slowly and steadily till within 50 fathoms of the bottom, when it increases suddenly to the extent of upwards of 15 per cent., mainly at the expense of the Nitrogen, which falls upwards of 14 per cent., the Oxygen remaining nearly stationary. The amount of Organic matter seems to be very uniform, varying, apparently irregularly, within narrow limits.

Depth in Fathoms.	Specific Gravity.	Percentage of Carbonic Acid.	Percentage of Oxygen.	Percentage of Nitrogen.	Total Percentage of Gases.	Oxygen required to neutralize Organic matter in 250 c. c. of water.
						gramme.
862	1027·5	48·23	17·22	34·50	3·5	·001
800	1027·7	33·75	17·79	48·46	2·8	·001
750	1027·5	31·92	18·76	49·32	2·8	·0012
700	1027·5	31·02	19·31	49·66	2·2	·0013
650	1027·5	30·00	19·80	50·20	2·4	
600	1027·5	28·34	20·14	51·52	2·4	·0005
550	1027·5	29·06	20·70	50·24	2·6	·0009
500	1027·5	27·26	....	....	2·2	·0014
450	1027·5	24·73	22·18	53·09	2·8	·0005
400	1027·5	29·73	22·71	47·51	2·5	·0014
350	1027·3	....	....	....	....	·0015
300	1027·3	....	....	....	....	·0018
250	1027·3	....	....	....	....	·0019
200	1027·3	....	....	....	....	·0017
50	1027·2	30·73	25·23	43·84	2·2	·0014
Surface	1027·5					

59. On the 28th we dredged in 1207 fathoms (Station 43), with a bottom of ooze. A large *Fusus* of a new species (*F. attenuatus*, Jeffreys) was brought up alive, with two or three *Gephyrea*, and an example each of *Ophiocten Kröyeri* and *Echinocucumis typica*. We again dredged on the 29th and 30th, gradually drawing in towards the coast of Ireland in 865, 458, 180, and 113 fathoms successively (Stations 44, 45). In 458 fathoms (Station 45) we procured a broken example of *Brisinga endecacnemos*, previously taken by Mr. Jeffreys off Valentia, and a number of interesting Mollusca; and in 458 and 180 fathoms (Stations 45 and 45*a*) an extraordinary abundance of animal life, including many very interesting forms—*Dentalium abyssorum*, *Aporrhaïs Serresianus*, *Solarium fallaciosum*, *Fusus fenestratus*, a beautiful Ophiurid, the type of a new genus allied to *Ophiura*, remarkably large specimens of the commoner forms, *Ophiothrix fragilis* (for example), nearly a foot and a half from tip to tip of the arms, and brilliantly coloured, abundance of *Caryophyllia Smithii*, and of all the ordinary deep-water forms of the region. About midday on Saturday, the 31st of July, we steamed into Queenstown. Having coaled at Haulbowline on Monday the 2nd of August, we were moored in the Abercorn basin, Belfast, after a pleasant return passage up the channel, on the evening of Wednesday the 4th.

Third Cruise. (Chart, Plate 6.)

60. In accordance with the original Programme (§ 29), the Third Cruise was devoted to the re-examination, on a more minute and extended scale, of

the region of the "Warm and Cold Areas" traversed last year in the 'Lightning,' with the special view of determining, if possible, (1) the Physical conditions on which depends the remarkable contrast then discovered between their *bottom*-temperatures, the Sea-bed being of nearly the same depth throughout, and their *surface*-temperatures being alike; and (2) the influence of this difference upon the distribution of Animal life, and on the nature of the Sea-bed itself.

61. As it was requisite that the boilers of the 'Porcupine' should be thoroughly cleansed after her return from the Second Cruise, we did not leave Belfast (to which port she had gone round from Cork) until Wednesday, August 11th; when we made direct for Stornoway as our final point of departure, arriving there on Friday the 13th. Having taken in as much coal as could be safely stowed on deck, as well as below, we left Stornoway on the afternoon of Sunday the 15th, and proceeded in the direction of the spot on which we had made our most successful dredging of last year ('Lightning' Report, § 16), and which we had come to call the *Holtenia*-ground*. Our dredging on this ground (Station 47) again proved remarkably successful, bringing up numerous specimens of *Holtenia*, of *Hyalonema* (one of them constituting a new species), of *Adrasta infundibulum* (a type allied to *Hyalonema*), and of *Tisiphonia* (a remarkable genus of Siliceous Sponges, obtained, like *Holtenia*, for the first time last year, of which a description, by Prof. Wyville Thomson, will soon be presented to the Royal Society), besides many other specimens of great interest, some of which appear to be new types. The experience of the 650 fathoms' dredge last year having led us to put aside and preserve the *siftings*, instead of attempting to pick them over at the time, we have since found them to yield an extraordinarily rich harvest of *Foraminifera*, including not merely the types mentioned in the 'Lightning' Report (§ 16), but a great number of others, especially of the *Arenaceous* Order, in which the shelly covering is replaced by a "test" composed of sand-grains more or less firmly cemented together. Although the *Holtenia*-ground lies within the Warm area, the Sea-bed of which is ordinarily covered by *Globigerina*-mud ('Lightning' Report, p. 190), yet this mud here contains a considerable admixture of sand, obviously derived from the Cold area with which it is here in immediate proximity. For this sand, when separated from the *Globigerina*-mud, corresponds precisely in its character with that of the Cold area, being especially distinguished by the admixture of particles of Augite and other minerals having an undoubtedly Volcanic source. This admixture is very perceptible to the experienced eye in the "tests" of *Astrorhiza* and other Arenaceous Foraminifera abundant

* The largest of the extraordinary Vitreous Sponges dredged in this locality last year has been described by Prof Wyville Thomson, in a Memoir presented to the Royal Society on June 17, and since published in the Philosophical Transactions for 1869, under the generic name *Holtenia*, in compliment to our excellent friend Amptman Holten, the Governor of the Faroe Islands.

in this locality, as well as in those of *Lituola* and other Arenaceous types inhabiting the Cold area, where the bottom is formed by sand and small stones alone.

62. It is not a little curious that one of the new types* discovered last year in the 650 fathoms' dredging ('Lightning' Report, § 19), which was made in a part of the Warm area far removed from the borders of the Cold, was now found to occur here also, but with a remarkable difference in the structure of its "test." Its shape is fusiform, generally somewhat curved, not unlike a §; and it has only one undivided cavity, with a tubiform aperture at each end. Now in the true Cretaceous area, where sand-grains are scarce, but sponge-spicules abound, this Rhizopod constructs its "test" almost entirely of sponge-spicules, laid with most extraordinary regularity, a sand-grain being interposed here and there to fill up a vacuity left by the oblique crossing of the spicules. But in the *Holtenia*-ground, where sand is abundant, "tests" of precisely the same general form and proportions are built up almost entirely of sand-grains cemented together; sponge-spicules, however, being invariably used to form the tubiform mouths, and the mouth thus formed being sometimes prolonged like a proboscis.—It is difficult to conceive how creatures which seem nothing more than particles of animated jelly, without "organs" of any kind, can exert so remarkable a power of selection and construction as is shown in the "tests" of some of these Arenaceous *Foraminifera*. There are none which are more symmetrically constructed than the triradiate *Rhabdammina*; each of its three very slender arms, which diverge at equal angles, being a cylindrical tube, built up of sand-grains of very uniform size, united by a firm cement which contains a considerable proportion of Phosphate of Iron. This tube is beautifully smoothed off internally; and it is no rougher externally, in proportion to its size, than any wall would be that is built of rough-hewn stones arranged by the hands of a most dexterous mason. The only structure with which we are acquainted that is at all comparable to it in workmanship is the sandy tube of the *Pectinaria*, one of the Tubicolar *Annelids*, a creature comparatively high in the scale of organization.

63. It was here that we employed for the first time an addition to our Dredging apparatus devised by Capt. Calver, who, having noticed that animals frequently came up attached to the part of the dredge-rope that had lain on the ground, or to the net of the dredge itself, justly reasoned that if the Sea-bottom were *swept* with hempen brushes, they would probably bring up many creatures that might escape the *scraping* of the dredge. These brushes were made of bundles of rope-yarn teazed out into their separate threads, and tied together at the top, so as closely to resemble the

* This type was described by Dr. Carpenter in a Memoir presented to the Royal Society, June 17th, "On the Rhizopodal Fauna of the Deep Sea," as a form of the *Proteonina* of Prof. Williamson. He has subsequently been led to doubt, however, whether that designation can be properly applied to it.

ordinary "swabs" used on board ship. An iron rod was attached to the bottom of the dredge, and carried out about two feet on either side of it; and it was to these projecting portions (resembling the studding-sail-booms extended from a yard-arm) that the "hempen tangles" were attached by Capt. Calver, who rightly judged that if they were attached to the bottom of the dredge itself, they would only bring up what the dredge had passed over and crushed. Though the use of these "tangles" added much to our "hauls" on the *Holtenia*-ground, especially on a subsequent occasion (§ 86), yet it was on the hard bottom of the Cold area that their value became especially apparent, the "tangles" often coming up laden with the richest spoils of the Ocean-bed, when the dredge was nearly empty (§ 74).

64. Our course was now directed slowly N.N.W., towards the southern edge of the Faroe Bank, Soundings being frequently taken, that we might determine the boundary in this region between the Warm and the Cold areas. The *minimum* temperature on the *Holtenia*-ground, as shown by the "protected" Thermometers, was a little under 44°, the depth being 540 fathoms; and this accorded very closely with the temperature of 47°·3 observed in the same spot last year, when the requisite correction was applied for pressure. A Sounding taken on the afternoon of the next day, at Station 49 (Lat. 59° 43′, Long. 7° 40′), showed a somewhat less depth, viz. 475 fathoms, and a slightly higher *minimum* temperature, 45°·4. In the evening of the same day another Sounding was taken (Station 50), and it was found that the depth had diminished to 355 fathoms, whilst the *minimum* temperature had risen to 46°·2. A Sounding taken early the next morning, however, at Station 51 (Lat. 60° 6′, Long. 8° 14′), showed a *minimum* of 40°, with a depth of 440 fathoms; and this depression of temperature led us to surmise that we were here passing from the Warm into the Cold area. The correctness of this surmise was soon proved; for a Sounding taken at about 20 miles to the north, at Station 52 (Lat. 60° 25′, Long. 8° 10′), gave a *minimum* temperature of 30°·6, though the depth had diminished to 384 fathoms!

65. In order to ascertain more particularly the conditions of this very remarkable depression, we requested Capt. Calver to ascertain the temperature at depths progressively increasing by 50 fathoms; and it was thus shown (1) that the *minimum* temperature *is* that of the bottom, as had been argued in the 'Lightning' Report (p. 189) to be probably the case; (2) that this *minimum* is nearly reached at a depth of 300 fathoms; (3) that the decrease of temperature is by no means uniform, but that whilst it takes place in the first 200 fathoms at nearly the same rate as in the most northerly stations previously tested in the First Cruise, there is a rapid and extraordinary diminution, amounting to more than 15°, between 200 and 300 fathoms. (See Table I. p. 456.) This diminution can scarcely be accounted for on any other hypothesis than that of a stream of frigid water passing under the warmer and more superficial stratum.—It is worthy of note that in this spot we found evidence, in the rounded form of the stones

and gravel brought up by the dredge, of a more decided *movement* of water than is presented in the Cold area generally, the bottom of which generally consists of fine sand, sometimes with an admixture of clay, including stones but little rolled. And as our subsequent Soundings have led us to believe that we were here on the western border of the Cold area, and that its stream of frigid water is reduced at the same time in breadth and depth, before discharging itself into the deep Oceanic basin (§ 104), a more rapid movement is precisely what might be expected.

66. Altering our course now to the E.S.E., we took another Sounding on the evening of the same day (Station 53), after a run of about 25 miles, and found the depth increased to 490 fathoms, and the *minimum* (which we shall now call the *bottom*) temperature reduced to 30°. This course having been continued during the night, we found ourselves (Station 54), early on the morning of August 19th, in Lat. 59° 56′ and Long. 6° 27′, where the depth was 363 fathoms, and the bottom-temperature 31°·4. It was thus obvious that we were still in the Cold area, although we had come back almost exactly to the latitude of Station 50, and were more than twelve miles to the south of the lowest parallel to which we had traced it last year. (We subsequently traced it, at Station 86, about nine miles still further south.) The coincidence of Depths as well as of Latitudes between Stations 50 and 54, with deeper water both north and south of them, shows that the bed of the channel here rises into a ridge, which has probably something to do with the direction of the course of the flow along its bottom.—We then again turned northwards, and in the afternoon of the same day found that our depth (Station 55) had increased to 605 fathoms, whilst the bottom-temperature was somewhat below 30°. Our Soundings were frequently repeated in this part of the Area, with great uniformity in their results, both as to Depth and Temperature; and our Dredging operations were carried on with little intermission. As the wind and swell were very moderate (although we were here almost constantly in a cold damp mist, which sometimes gave place to a mizzling rain), it was found convenient to put the dredge over soon after midnight, and to let it drag until about 4 A.M., hauling it in at the beginning of the morning watch. In this manner a rich harvest was frequently obtained. The general results of our Zoological exploration of the Cold Area may be best stated hereafter (§§ 74–80) in a collective form.

67. As we wished to examine the shallow bank of 170 fathoms in the middle of the Cold area, upon which we dredged last year ('Lightning' Report, § 13), our course was now directed to the spot on which it had been laid down in the Chart of the 'Lightning' Expedition; but we did not succeed in falling-in with it. The explanation of our failure seems to lie (1) in the extremely limited area of this bank, as shown by the great depth of water found in the 'Lightning' soundings on either side of it; (2) in the circumstance that both last year and this year, while we were working over this ground, the sky was so overcast for several days together, that it was impos-

sible to fix the place either of the 'Lightning' or of the 'Porcupine' by observation; and (3) that a "dead reckoning" cannot be kept with any considerable exactness when the ship is drifting with a dredge attached to it during a great part of the twenty-four hours.—Hence either the place of the bank may not have been precisely laid down in the 'Lightning' Chart; or a corresponding error of a few miles may have been made in estimating the place of the 'Porcupine.' How exactly accordant were the points determined by observation in the two Expeditions is shown by the precision with which Captain Calver twice placed us on the *Holtenia*-ground (§§ 61, 86), though approaching it in each case in a direction different from that in which we came upon it last year.

68. Pursuing our exploration about thirty miles further eastwards in the same parallel, we sounded on the afternoon of the 20th in 580 fathoms (Station 59, Lat. 60° 21′, Long. 5° 41′), and found the bottom-temperature 29°·7, which was nearly the lowest anywhere met with. From this point, which was on the line of Soundings between the Orkney and Faroe Islands previously taken in the 'Bull-dog,' we again turned our course northwards for Thorshavn, as it was our intention to make this our point of departure for the exploration of that north-eastern portion of the channel which lies between the Faroe and the Shetland Islands. The weather having now cleared, we had on the morning of Saturday the 21st a most beautiful run along the series of remarkably formed islands which we had last year only seen dimly through their covering of mist; and on anchoring at Thorshavn in the afternoon, we received a cordial greeting from our excellent friend Governor Holten, who, having been forewarned of our probable visit, and having had our vessel in view for some hours, at once came off in his barge to welcome us.

69. The apparently settled state of the weather encouraged us to hope that we might be able to avail ourselves of this opportunity of visiting Myling Head, the remarkable precipice which forms the North-western point of Strömoe, the principal island of the Faroe group, and which falls 2100* feet perpendicularly, its summit even slightly overhanging its base, so that a stone let fall from it drops into the sea beneath. On inquiring from the Governor as to the best means of carrying our wish into effect, he informed us that the tide runs so strongly round the islands, that if we started with the morning flood, and our vessel kept its speed in accordance with the rate of the tidal wave, we should be able to make the whole circuit in six hours; but that if we should attempt the expedition in any other mode, we should be tediously delayed by the strength of the opposing tide. As we learned that high water would occur on the following Monday morning at 4 o'clock†, we made

* The height of Myling Head is commonly stated at 2500 feet; but the above estimate is based on an observation made a few years since with an Aneroid barometer by the Authors of "The Cruise of the Yacht 'Maria' among the Faroe Islands."

† It is worthy of mention that a discrepancy between the Ship's time and the Island time (as indicated by the Church clock) having led us to inquire into the mode in which

our arrangements for an early start; and invited our kind host and hostess to give us the pleasure of their company. The fine weather lasted throughout Sunday, two consecutive days of such brightness being a most unusual occurrence in this locality; but early the next morning the Faroese climate vindicated its character by a copious downpour of rain, which put our start at 4 o'clock out of the question, and, for the reason just mentioned, obliged us to give up the excursion altogether.

70. Our good fortune in regard to weather returned to us on the following day; when we left Thorshavn (Aug. 24th) about noon, shaping our course about East by South, so as to cross the channel separating the Faroe from the Shetland Islands, the depth of which had been indicated by previous Soundings to be in some parts considerable. Our first two Soundings showed that we were still over a plateau at little more than 100 fathoms from the surface; but a third Sounding taken in the evening after a run of about 80 miles, gave us a depth of 317 fathoms, and a bottom-temperature of 30°·1. It became evident, therefore, that we were here again in the course of the frigid stream; and we looked with much interest to the phenomena it would present in a still deeper part of the channel. Having kept the same course under easy steam during the night, we took a Sounding the next morning at Station 64 (Lat. 61° 21′, Long. 3° 44′); and found that the depth had increased to 640 fathoms, and that the bottom-temperature was somewhat below 30°. The dredge having been put down, the "haul" was a less satisfactory one than usual, though one very valuable specimen (a large example of the *Pourtalesia* already mentioned, § 36) was obtained here; and in a subsequent trial the dredge came up empty. As this result appeared due to the circumstance that the drift of the ship was too great, in consequence of an increase of wind and swell, to permit the dredge to hold the ground, it was determined to devote the morning to a series of Temperature-soundings taken at every 50 fathoms from the surface downwards. This was very satisfactorily accomplished, with the result shown in Table I. (p. 456), from which it appeared that, with a lower surface-temperature than in the series previously taken (§ 65), the rate of decrease during the first 150 fathoms was nearly the same, but that the rapid descent of the thermometer which showed itself at Station 52 between 200 and 300 fathoms, here began somewhat earlier, and proceeded somewhat more gradually, with the result, however, of bringing down the temperature to 32° at a little below 300 fathoms, the whole of the water beneath that

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the latter was regulated, we found that as there is not even a Sun-dial in the Islands, *the time is kept by the turn of the tides*, the periods of which are precisely known for each day of the lunation. As nearly all the intercouse between different villages and farm-houses is carried on by water, and as every Faroese is a boatman and fisherman as well as a farmer, it is not to be wondered at that he should be practically versed in the periodical changes of the currents by which his power of locomotion is so greatly influenced, and that these should take the place of the meridian passage of the sun (which he has no means of observing with precision) as his best time-regulators.

depth, down to the bottom of 640 fathoms, on which the temperature is 30°, being of icy coldness.—Thus the entire mass of water in this channel is nearly equally divided into an upper and lower stratum,—the *lower* being *an Arctic stream* (so to speak) of nearly 2000 feet deep, flowing in a S.W. direction, beneath an *upper* stratum of comparatively warm water moving slowly towards the N.E.; the lower half of the latter, however, having its temperature considerably modified by intermixture with the stratum over which it lies.

71. Keeping still on the same course through the following night, we took a Sounding early the next morning (Station 65), which showed that we had crossed the deepest part of the channel, the depth having here diminished to 345 fathoms; the bottom-temperature, however, was still most characteristic of the Cold area, being almost exactly 30°, the lowest we had met with at that comparatively moderate depth. This circumstance, taken in connexion with the earlier descent just noticed, corresponded well with the fact that the line between Lat. 61° and Lat. 62° on which we had now crossed this channel, is nearer the source of the frigid stream than the lines between lat. 60° and $60\frac{1}{2}$° in which we had at first traversed it.

72. On the afternoon of the same day (Aug. 26), we again took a Sounding, which gave us the still further diminished depth of 267 fathoms; and here (Station 66), with a *surface*-temperature of $52\frac{1}{2}$°, which was but slightly above that of the previous Sounding, we found the *bottom*-temperature to be 45°·7. Now this was very nearly 12° above the temperature taken *at the same depth* at Station 64; whilst it was nearly 16° above the temperature last taken on a bottom only 78 fathoms deeper, at a Station distant only 18 miles. Even this slight difference of depth, however, seems fully adequate to explain the remarkable contrast between the bottom-temperatures of these two Stations; for, as already shown, the Arctic stream, in virtue of its greater Specific Gravity, occupies only that portion of the channel of which the bottom lies below about 320 fathoms' depth, so that no part of it will flow over that portion of the bank of the channel which has a depth of only 267 fathoms. The bottom on this bank, therefore, will be overlaid by the upper (warm) stratum alone; and as the lower half of this is not here subjected to the reduction of temperature which it sustains when underlaid by the frigid stream, the bottom will have the temperature characteristic of the Warm area, though not geographically included in it.

73. By the next morning we had come upon the shallow plateau on which the Shetland islands are based; and as we wished to examine some points in the Geographical distribution of the Fauna inhabiting this locality, we ran past the northern point of the group, and devoted the day to dredging at about thirty miles to the east, on what is known as the Haaf, or deep-sea fishing-ground. Our dredging on this plateau was not very productive as regards variety; but it brought up certain types in such extraordinary number as to show how abundantly they must be diffused over the Sea-bed.

The most remarkable instance of this occurred in regard to the *Echinus Norvegicus*, a small sea-egg about the size of the top of the finger. The "hempen tangles" came up so laden with these, that a very moderate estimate would place the number obtained in one "haul" at 20,000, whilst some of our party deemed it to be nearer 50,000. This had formerly been accounted a rare species, of which it was considered a piece of good fortune to find one or two at a time, and was first met with in abundance in Mr. Jeffreys's Shetland Dredgings.—On the following day (Aug. 28th) we anchored in Lerwick harbour, where it was requisite for us to replenish our coal, as well as to obtain a further supply of jars and spirit, the abundance of our collections having nearly exhausted what we had supposed to be our ample provision of both.

74. Without entering into details which will be more appropriately given hereafter, we may say that our exploration of this Cold area, which we had been led by the results of our last year's dredging to regard as comparatively poor in Animal life (as, indeed, we should still have believed it to be, had our knowledge of its Fauna been restricted to the contents of the Dredge, instead of being chiefly obtained by the instrumentality of our "hempen tangles"), greatly extended our ideas of the conditions of animal existence; for we found the Sea-bottom, at depths of from 350 to 640 fathoms, at a temperature at or below the freezing-point of fresh water, almost, if not quite, as thickly covered with Animals as in the richest parts of the Warm area. These animals were mostly, however, of a very different character. In the first place, the *Globigerina*-mud was entirely wanting, its presence being sharply bounded by the limit of the Warm area, and its composition being modified even on the borders of this by an admixture of the Sand characteristic of the Cold area (§ 61). Now this fact appears to be a conclusive disproof of the hypothesis that the accumulation of the shells of *Globigerinæ* on the bottom of the ocean is due to their having fallen to the bottom after death, their lives having been passed at or near the surface. For admitting that they have been occasionally captured by the tow-net*, this only proves that they *can* float; whilst, on the other hand, our examination of specimens freshly dredged from great depths enables us to state with positiveness that their sarcodic bodies present all the attributes of life which are exhibited by those of the *Rotaline* forms whose attachment to solid bodies made it clear that *they* must pass their lives at the bottom, and of the *Arenaceous* types which can only there obtain the materials for their "tests." Now since, as we have repeatedly pointed out, the *surface*-temperature of the Cold area does not differ from that of the Warm, and this equality extends to the first 150 or 200 fathoms, there seems no reason whatever why a deposit of *Globigerina*-mud should not take place on the bottom of the Cold area, if such deposit be due to the accumulation of the dead shells of individuals which had spent their

* See Major Owen's account of the Surface-Fauna of the Atlantic; in Journal of the Linnean Society, vol. ix. p. 147.

lives at or near the surface. Whereas if they really inhabit during their lives the bottom on which they are found in such extraordinary abundance, we have at once the explanation, in the difference of temperature between the two Areas, of their definite restriction to the Warm *.

75. The simple Protozoic type represented by the *Globigerinæ*, however, has its parallel in the Cold area, though presenting itself under a very different aspect. Every Zoologist now recognizes the close Physiological relationship between *Foraminifera* and *Sponges*, notwithstanding their wide morphological divarication; and we believe them to agree in this most important particular,—that the animals of both groups are capable of obtaining their nutriment by the imbibition of the Organic matter diffused through sea-water (§ 23), just as they derive from the same source the Carbonate of Lime or the Silex which forms the Mineral basis of their skeletons. The *Sponges* of the Cold area were very diverse in type, and some of them extremely numerous individually. Magnificent specimens of most of the species hitherto known only as inhabitants of the deep water off Shetland were found to be very generally diffused; but the most peculiar and novel type of this group was met with at our very entrance upon the Cold area (Station 52), and presented itself in such abundance at almost every other Station having the same bottom-temperature, that we came to look upon it as one of the most characteristic inhabitants of this area, covering (as it seems to do) hundreds of square miles of the Sea-bed. This Sponge is distinguished by the possession of a firm branching axis, of a pale sea-green colour, rising from a spreading root, and extending itself like a shrub or a large branching *Gorgonia*. The axis is clothed with the soft pale-yellow sarcodic substance of the Sponge; and both axis and sponge-substance are crowded with Siliceous spicules, resembling those of *Esperia*, a well-known Mediterranean and Adriatic form, near which our Sponge must be placed, though it clearly forms the type of a new genus. It is curious that scarcely even fragments of this Sponge came up in the dredge, our specimens being almost entirely obtained through the instrumentality of the "hempen tangles" attached to it. We had last year obtained some minute fragments of the axial portions of the branches of this Sponge; but they were so imperfect that we had not been able to make out their true characters.

76. The most remarkable *Foraminifera* obtained in this area belonged to the *Arenaceous* Order; and it is singular that whilst very abundant in the localities in which they were met with, they seemed very restricted in Geographical range. Thus at Station 51, which was intermediate between the

* Mr. Jeffreys desires to record his dissent from this conclusion, since (from his own observations, as well as those of Major Owen and Lieut. Palmer) he believes *Globigerina* to be exclusively an *Oceanic* Foraminifer inhabiting only the superficial stratum of the sea; he considers also that the strength of the submarine current in the Cold area is sufficient to sweep away and remove these very slight and delicate organisms. According to him the protrusion of pseudopodia is the only satisfactory proof that the *Globigerina* is living.

Warm and the Cold area (§ 64), the "tangles" brought up an immense number of tubes usually from $\frac{3}{4}$ inch to 1 inch long, and about $\frac{1}{8}$ of an inch in diameter, composed of sand-grains cemented together. These tubes often presented an appearance of segmentation externally; and they were at first supposed to be a modification of the straight chambered *Lituolæ* obtained on the bank of the Cold area last year, though differing from them in having no definite prominent mouth. On breaking them open, however, it was found that the cavity is not divided into chambers by interposed septa, as in *Lituola*, but that it is continuous throughout, though traversed in every part of its length by irregular processes built up partly of sand-grains and partly of sponge-spicules, strongly resembling those which have been recently described by Mr. Brady in the gigantic Foraminiferal fossil *Loftusia*, and which present their most symmetrical arrangement in the yet more gigantic fossil *Parkeria* described in the same Memoir by Dr. Carpenter*. These arenaceous processes lie in the midst of the sarcodic body, which fills the whole of the cavity without any division into segments, and which communicates with the surrounding medium, at what appears to be the free extremity of the tube, by irregular spaces left between the agglutinated sand-grains that form a rounded termination which nearly closes it in. At the other extremity, however, the tube is so uniformly open in the numerous specimens that have been examined, and so generally presents an appearance of fracture, that there seems strong ground for believing that this type (to which we assign the generic designation *Botellina*) must grow attached by the lower end of its tube to some fixed base. It is singular that while this fabric presented itself at no neighbouring Station, the "tangles" brought up in the comparatively shallow water near Shetland a number of tubes, which, though of somewhat larger size, and having their sand-grains yet more regularly agglutinated, presented so close a general resemblance to our *Botellina*, as strongly to suggest a similarity of character. This idea, however, was soon dispelled by further examination; for the tubes, when broken open, proved to be as smooth internally as they were externally, and to be lined by a definite membrane; in addition to which they were freely open, and their edges rounded off, at what appeared to be their last-formed extremity; so that there remained no doubt that they had been constructed by some Tubicolar *Annelid*.—The true chambered *Lituolæ* found last year on the 170 fathoms bank, in the Cold area ('Lightning' Report, § 13), were not met with this year; but monothalamous "tests," closely resembling them in external appearance, were obtained in abundance at Station 64.—With the exception of these *Arenaceous* types, the *Foraminifera* met with in the Cold area were not remarkable either for number or variety; and, as compared with their extraordinary abundance in the Warm area (§ 87), were rather "conspicuous by their absence."

77. The most marked feature in the Fauna of the Cold area was undoubt-

* Philosophical Transactions, 1869, p. 806.

edly its extraordinary richness in *Echinoderms*, the prevalent types being of a decidedly Boreal and even an Arctic character. During the course of our exploration we met with nearly all the members of this group which have been described by Scandinavian naturalists as inhabiting the coast and fiords of Norway; and we were particularly struck with the abundance of the beautiful *Antedon* (*Comatula*) *Eschrichti*, which has hitherto been obtained only from the neighbourhood of Iceland and Greenland. On the other hand, such of the characteristically Southern forms as here presented themselves were so reduced in size that they might almost be accounted specifically distinct, if it were not for their exact conformity in general structure; the *Solaster papposa*, for example, being dwarfed from *six* inches in diameter to *two*, and having never more than ten rays, and the *Asteracanthion violaceus* and *Cribella oculata* being reduced in like proportion. One striking feature of the group, however, showed no modification. The *coloration* of these animals, though brought up from a depth of 500 or 600 fathoms, was as rich and beautiful as that of their littoral representatives. Their orange, violet, and scarlet blended admirably with the pale green of the large Sponge-stem when grouped together in a basin of water; and we were led to wonder, on the one hand, how such vivid hues could be produced in the absence of light, and, on the other, what purpose they can serve in the economy of animals which live on a bottom supposed to be entirely unillumined by solar rays, and which only exhibit these hues when brought within reach of daylight. Whilst our explorations in the Cold area have thus added to the British Fauna a large number of types of *Echinoderms* which had been previously supposed to lie altogether beyond its range, they have also brought up several forms which altogether are new to science, some of them of very considerable interest. Thus in the Shetland channel we procured a full-sized specimen of the remarkable Clypeastroid *Pourtalesia*, of which young examples had been obtained in the First cruise (§ 36), and a very singular Asterid allied to *Pteraster*, which is covered with a regular brush of long paxillæ. Since, for the reason formerly mentioned, we have found ourselves precluded from dedicating the former of these types (as we had intended) to our friend Capt. Calver, we propose to give the generic name *Calveria* to the latter, with the specific designation *hystrix*.

78. Of the *Crustacea* of the Cold area, many are most distinctly referable to the Fauna of Spitzbergen, whilst others are characteristically Norwegian. We were struck with finding attached to the "tangles," on nearly every occasion, numerous specimens of very large *Pycnogonids*, measuring, when their limbs were extended, as much as four or five inches across. The comparatively small forms of these animals that are common on our own shores are commonly found imbedded in the gelatinous layer that envelopes the surfaces of *Algæ*; and the suctorial character of their mouths, taken in connexion with the feebleness of their locomotive powers, seems to indicate that they are nourished by the ingestion of this material. Hence it is probable that their gigantic representatives living on the Sea-

bottom make the same use of the sarcodic substance of the *Sponges* and *Rhizopods* which they there meet with *.

79. The *Mollusca,* which in the preceding Cruises usually constituted the principal results of the dredgings, were here quite subordinate, as regards both number and variety, to the groups already alluded to; and the difference between the Molluscan Fauna of the Cold and that of the Warm area was not by any means as great as was shown in other groups. One of the most interesting types which we met with was a Brachiopod found living, at Station 65 in the Shetland channel, at a depth of 345 fathoms, and a bottom-temperature of 30°, viz. the *Terebratula septata* of Philippi, =*T. septigera* of Lovén. A variety of this species, from the Pliocene beds of Messina, has been described and figured by Prof. Seguenza under the name of *Waldheimia Peloritana*; and it is clearly the same as the *Waldheimia Floridana,* found in the Gulf of Mexico by Pourtales, which our own numerous specimens so considerably exceed in size as to show that its most congenial home is in frigid water. A single specimen was found of another remarkable Brachiopod, the *Platydia anomioïdes* of Scacchi (or *Morrisia* of Davidson), hitherto supposed to be restricted to the Mediterranean. Since in this case, also, the size of our specimen greatly exceeds that of the Mediterranean examples of the same species, being nearly double, the presumption is strong that its original home is in the Boreal, perhaps even in the Arctic region.

80. Only a small number of *Fishes* were procured, but their scarcity may probably have been chiefly due to the unsuitableness of the dredges as a means of their capture. The few species taken have been examined since our return by Mr. Couch. The list includes a new generic form intermediate between *Chimæra* and *Macrourus,* which was brought up from a depth of 540 fathoms in the cold area; a new species of a genus allied to *Zeus*; a new *Gadus* approaching the common Whiting; a new species of *Ophidion*; the type of a new genus near *Cyclopterus*; *Blennius fasciatus* (Bloch), new to Britain; *Ammodytes siculus*; a fine new *Serranus*; a new *Syngnathus*; with several others, which will be described in full hereafter.

81. Having obtained the requisite supplies at Lerwick, we left the harbour about noon on the 31st of August, and ran southwards until we had passed Sumburgh Head, when we steered towards the west, our object now being to examine the southern portion of the channel between the North of Scotland and the Faroe islands with the same minute attention which we had previously bestowed on its northern portion. Early the next morning we sounded (Station 71) in Lat. 60° 17′, Long. 2° 53′, and found the depth to be 103 fathoms, and the bottom-temperature 48°·6, the tem-

* It seems worth while here calling to mind that a *Pycnogonid* of even yet more gigantic dimensions was among the specimens obtained by what was at that time considered very deep dredging in Sir James Ross's Antarctic Expedition. See 'Lightning' Report, p. 178, note.

perature of the surface being 52°·7. In the afternoon of the same day (Station 74) the water had deepened to 203 fathoms, while its bottom-temperature had diminished to 47°·6, the surface-temperature being 52°·6. Another Sounding (Station 75) taken only two and a half hours later, and at a distance of no more than 10 miles from the preceding, gave a depth of 250 fathoms, and a bottom-temperature of 41°·9—a reduction which clearly showed that the frigid current exerts no inconsiderable influence in this locality, the temperature at Station 66, at the slightly greater depth of 267 fathoms, having been 45°·7. Having run about 30 miles during the night, we found ourselves early the next morning in Lat. 60° 36′, Long. 3° 58′; and here (Station 76), with a surface-temperature of 50°·3, we found the bottom-temperature 29°·7, at a depth of 344 fathoms, as at Station 65. Keeping on our westward course for 25 miles, we took another Sounding (Station 77) at noon of the same day, which gave us a depth of 560 fathoms, and a bottom-temperature of 29°·8. This Station was only about twelve miles to the S.S.E. of the first point (Station VI.) at which we came upon the Cold area last year; and it was interesting to have so complete a confirmation of the accuracy of that observation, which had given us at the depth of 510 fathoms a temperature of 33°·7, which, when corrected for pressure, would be 31°·6.

82. Changing our course to the southward, we found on the afternoon of the same day (Station 78), after a run of about 20 miles, that the depth had diminished to 290 fathoms, and that the bottom-temperature had risen to 41°·6; from which it appeared that the influence of the frigid stream was not quite so great, in proportion to the depth, as at Station 75, though still very decided. Keeping on to the southward during the night, we crossed the 100-fathom line, and found ourselves early in the morning (Station 79) in Lat. 59° 49′ and Long. 4° 42′, where the depth was only 92 fathoms, and the bottom-temperature 49°·4, with a surface-temperature of 52°·3. It seemed obvious, therefore, that the influence of the frigid stream did not extend over this shallower portion of the bed of the channel; and this conclusion was confirmed by the Soundings which we took at short intervals after altering our course to the N.W., so as to pass again from this plateau into deep water. For after steaming 7 miles we found the depth 92 fathoms, and the bottom-temperature 49°·4; proceeding 7 miles further, the depth was found to have increased to 142 fathoms, while the bottom-temperature was still 49°·1; but a continuance of the same course for only 8 miles showed that the bottom rapidly descends here, as on other parts of the southern border of this channel, the depth at Station 82 having increased to 312 fathoms, whilst the temperature fell to 41°·3, showing a very precise accordance with the condition of Station 78. We were here only about 7 miles to the S.E. of our last year's Station VII., where the depth was 500 fathoms, and the bottom-temperature 32°·2, which when corrected for pressure, would be 30°·1; and it was thus very interesting to see how considerably the bottom-temperature

varied with the depth, on the border of that deeper portion of the channel which gives passage to the Arctic stream. In order to test this yet more completely, we proceeded about 7 miles to the northward (Station 83), so as to be almost exactly in the parallel of our last year's Station VII., but about 7 miles to the eastward of it; and here we found the depth to have increased to 362 fathoms, while the bottom-temperature had fallen to 37°·5. Comparing this, however, with the bottom-temperature of 29°·7, found at Station 76, at which the depth was rather less, it became obvious that the influence of the warm surface-current here extends to a greater depth.

83. Again changing our course to the S.W., in a direction nearly parallel to the 100-fathom line, so as to bring us to a part of the area not previously surveyed, we took a Sounding (Station 84) early in the morning of Saturday, Sept. 4th, in Lat. 59° 34′, and Long. 6° 34′; and found the depth to be 155 fathoms, and the bottom-temperature 49°·1, showing that we were again on a portion of the southern bank too near the surface to be affected by the frigid stream. And as, on sounding again (Station 85), after having run 6 miles in a northerly direction, we found the bottom-temperature to have only fallen to 48°·7, while the depth had increased to 190 fathoms, it was obvious that the same condition still existed. A further run of only 8 miles northwards, however, brought us suddenly into the Arctic stream; the depth (Station 86) being here 445 fathoms, and the bottom-temperature 30°·1.—These very rapid changes of Submarine Climate are of extreme interest in a variety of ways, but especially in their Zoological and Palæozoological relations, as will be shown hereafter.

84. As we were now again approaching a part of the Area which had been previously explored with sufficient minuteness for our present purpose, and as we desired to extend our survey into a part of the Warm area removed from the immediate influence of the Arctic stream, our ship's head was kept to the westward without any stoppage until the morning of Monday, Sept. 6th; when we reached Long. 9° 11′ in Lat. 59° 35′, this point being about 24 miles to the south of Station XIV. in our last year's Cruise. Here a Sounding gave us (Station 87) a depth of 767 fathoms, and a bottom-temperature of 41°·5; and as it thus became obvious that we were in the Warm area, we thought it desirable to obtain a set of *serial* Soundings, for comparison, on the one hand, with those obtained on the Cold area, and, on the other, with those taken in the former Cruises at similar depths on the border of the North Atlantic basin.—The results of these Soundings, given in Table I., p. 456, will be discussed hereafter; and at present it will be sufficient to state that while they show that the influence of the Warm stream here extends through the entire depth, they also indicate that this is modified below 500 fathoms by the frigid stream; the depression of temperature between 500 and 600 fathoms being almost exactly equal to that which presented itself between 100 and 500 fathoms. —Our dredge here came up with the extraordinary load mentioned in the

Introduction (§ 8) as having severely tested the efficiency of our donkey-engine; which, however, proved equal to its work, and landed on our deck *half a ton* of *Globigerina*-ooze, here showing very little intermixture with sand. Like our similar haul at Station XVI. last year, however, this mass contained but a small amount of the higher forms of Annimal life; and as a continuance of our course still further west did not seem likely to furnish any additional results of importance, and as there would have been a risk of exhausting our coal in steaming against a head-wind, we thought it better to change our course towards Stornoway, taking a direction that should bring us again on the ground which we had previously found most productive. In the afternoon of the same day we took another Sounding in Lat. 59° 26′ and Long. 8° 23′, on the line of our outward track in the second part of the 'Lightning' cruise last year, so as to establish the depth and temperature at an intermediate point between two distant stations; and we here (Station 88) found the depth to be 705 fathoms, and the bottom-temperature 42°·6, thus showing a close accordance with the nearest Soundings previously taken.

85. Continuing our easterly course during the night, but making slightly to the northward, so as once more to come upon the *Holtenia*-ground, we sounded early the next morning (Sept. 7) in Lat. 59° 38′, Long. 7° 46′; and found (Station 89) that the depth had diminished to 445 fathoms, whilst the temperature had risen to 45°·6,—thus confirming by *bottom*-soundings the inference we had been led to draw from the *serial* soundings taken at Station 87, that the influence of the frigid stream is exerted even in the Warm area at depths greater than 500 fathoms, in depressing the temperature of the body of water which it there meets, and with which it mixes. Another Sounding taken after a further run of 7 miles in the same direction, which brought us very near to Station 49, gave a similar depth and temperature; but the character of the bottom now indicated the proximity of the Cold area, the *Globigerina*-ooze being here mingled with Sand.

86. We now changed our course to the S.E., and after steaming about ten miles, put down our dredge with its "hempen tangles" upon what we were assured by Capt. Calver was the spot (as nearly as it could be determined) upon which we had made the *first* deep-sea dredging in this Cruise (§ 61); and the result of this *last* visit to our favourite ground was such as to surpass our most sanguine expectations. For the dredge and the tangles alike came up laden with such a collection of the "treasures of the deep," as we feel quite safe in asserting had never before been brought to the surface on any one occasion,—almost every specimen being such as would be accounted an important acquisition to Museums already most complete. *Holtenias* there were by the bucketful; *Hyalonemata* (one of them a new species) with their "flint-rope" covered with the parasitic *Palythoa,* and bearing at their summit the living *Sponge* of which the "flint-rope" constitutes the radix; the beautiful *Tisiphonia,* or mush-

room-shaped Sponge, in abundance; *Adrasta infundibulum*, another Vitreous Sponge allied to *Hyalonema*; and other types of the same group not yet described. The *Echinodermata* also were very numerous, and many of them very large; and they presented a great variety of most interesting types, nearly all of them being new to the British Fauna, though many had been previously described. It was especially interesting to note the very marked difference between the *Echinoderm-Fauna* of this region and that of the Cold area. With the exception of a few species which seem able to maintain their existence through almost any range of depth and temperature, they were all diverse; and whilst the mixture of decidedly Arctic forms, and the dwarfing of Southern types, gave a decidedly Boreal character to the Fauna of the Cold area, there was here a mixture of fully developed Southern types, among them a *Stichaster* either identical with or closely allied to a species described from Madeira. But the specimen of this group most interesting to us (perhaps the most remarkable capture made in the whole of our Cruise) was a large Echinid allied to *Astropyga* (belonging to the Family *Diademidæ*), having a perfectly soft and flexible test; the plates of the corona, though retaining their normal number and arrangement, being very thin and slightly separated from one another by the interposition of a flexible perisome, so that the test resembled an armour of chain-mail, instead of the cuirass with which the ordinary *Echinida* are enveloped. Two specimens of this remarkable type were obtained,—a perfect one at Station 89, and another, considerably injured, but still serving for anatomical investigation, on our *Holtenia*-ground. The perfect specimen is about 5 inches in diameter, and of a brilliant shade of crimson, altogether a most striking object. This form at once recalled the very singular fossil from the White Chalk, two specimens of which are in the British Museum, described by the late Dr. S. P. Woodward under the name of *Echinothuria floris*; and though we would not affirm the actual identity of the existing form with the old, there can be no doubt of their very close affinity, and of the persistence of this remarkable type of structure from the Cretaceous to the present epoch.—Here also we obtained a specimen of almost the only one of the Scandinavian Starfish that we had not met with on British ground, the *Asteronyx Lovéni*, a very interesting modification of the *Astrophyton* type, having the same general plan of structure, but having the arms simple, instead of being subdivided in the manner which has given occasion to the designation *Gorgonocephalus*. It is not a little curious that a dredging we subsequently took in the Minch, near the eastern shore of Skye, brought up six specimens of this rare Echinoderm, thus confirming a surmise previously formed, that the careful exploration of that channel would show that many types would be there found which have been hitherto supposed to be peculiar to Norway.

87. The *Foraminifera* obtained on this and the neighbouring parts of the Warm area presented many features of great interest. As already stated

(§ 61), several *Arenaceous* forms (some of them new) were extremely abundant; but in addition to these we found a great abundance of *Miliolines* of various types, many of them attaining a very unusual and some even an unprecedented size. As last year, we found *Cornuspiræ* resembling in general aspect the large *Operculinæ* of tropical seas, and *Biloculinæ* and *Triloculinæ* far exceeding in dimensions the littoral forms of British shores; and with these were associated *Cristellariæ* of no less remarkable size, presenting every gradation from an almost rectilineal to the Nautiloid form, and having the animal body in so perfect a state as to enable it to be completely isolated by the solution of the shell in dilute acid.—It is very interesting to remark that certain forms of this *Cristellarian* type are among the most characteristic Foraminifera of the Cretaceous as well as of various Tertiary deposits; and the similarity of some of these to existing forms is so close, that the continuity of the type from the Cretaceous epoch cannot be reasonably questioned. It is further interesting to note that it has a great bathymetrical range, no difference showing itself between the *Cristellarians* of our Warm area and those found in the preceding Cruises at nearly three times the depth.—The continuity of Foraminiferal life is further indicated by the occurrence in the *Globigerina*-ooze of a number of *Rotalian* forms which are peculiarly characteristic of the Fauna of the Cretaceous period.

88. The cumulative evidence which we have thus obtained in support of the hypothesis advanced last year ('Lightning' Report, p. 193) as to the uninterrupted continuity of the Cretaceous deposit on the North-Atlantic Sea-bed from the epoch of the Chalk-formation to the present time, will be more fully discussed hereafter. But as, with the exception of the subsequent dredging in the shallow waters of the Minch already referred to (§ 86), our Zoological exploration of the sea-bottom came to a conclusion with the extraordinary *climax* just described, we may here mention an idea which formed the subject of much discourse between us at this period.

89. It is, we believe, the general creed of modern Geologists, that all Calcareous rocks have had, either directly or indirectly, an Organic origin; and that the most perfectly mineralized condition of such rocks affords no evidence to the contrary, there being abundant evidence that all traces of organic structure may be completely obliterated by subsequent metamorphic action. Thus upheaved masses of recent Coral are frequently converted into subcrystalline Limestone, the organic origin of which would not be recognized by any feature in its molecular arrangement or composition; whilst a change often presents itself (as on the Antrim Coast) of a true Chalk into a subcrystalline Marble, under the combined influence of the heat and pressure occasioned by the intrusion of Volcanic rocks. Now since there can be no question that the Chalk-formation in its entirety owes its origin chiefly to the accumulation on the deep-sea bottom of the shells, or their débris, of successive generations of *Foraminifera* which lived and moved and had their being there,—and since there can be as little question

that there must have been deep seas at all Geological periods, and that the changes which modified the climate and depth of the sea-bottom were for the most part very gradual,—the question naturally arises whether we may not carry back the continuity of the accumulation of the Foraminiferal ooze on some part or other of the Ocean-bed into Geological epochs much more remote, and whether it has not had the same large share in the production of the earlier Calcareous deposits that it has undoubtedly had in that of the later. Though it is altogether beyond doubt that some beds of Carboniferous Limestone (for example) were simply Coral reefs, covered with waving Crinoids and swarming with Brachiopod and other Mollusks, there are other parts of this formation which seem to have been deposited in much deeper waters; and to these we should be inclined to ascribe a *Foraminiferal* origin. This hypothesis seems not only probable on general grounds, but is supported by several remarkable facts. It has long been known that certain beds of Limestone of Carboniferous age, in Russia and elsewhere, are almost entirely made up of an aggregation of Foraminiferal shells belonging to the genus *Fusulina**; and Prof. Phillips has described under the name *Endothyra Bowmanni*† a Foraminiferal type which seems nearly allied to *Fusulina*, and which he states to occur in great abundance with *Textularia* in the Mountain-limestone beds of the North of England. Again, Mr. H. B. Brady has lately shown us, in a thin layer of Clay occurring in the midst of Carboniferous-limestone beds near Newcastle, an accumulation of *Arenaceous* Foraminifera closely corresponding in type with the *Saccammina* of Sars, which we found to be abundant, in many of the deeper dredgings of the earlier Cruises, on the eastern border of the North-Atlantic Sea-bed.—To this question, however, we shall recur in the discussion of the General Results of our Deep-Sea explorations.

90. Thoroughly well satisfied with the success of our third Cruise, both in the confirmation and extension it afforded of the conclusions as to the climate we had ventured to draw from the comparatively few and scanty data we had obtained last year, and in the large mass of Zoological novelties we had collected, we now made for Stornoway, and arrived there on the evening of Wednesday, September 8th. If we had been free to dispose of the 'Porcupine,' we might have taken the opportunity of connecting the Third with the First Cruise, by exploring the deep bottom to be found about 200 miles to the west of the Hebrides, as far south as the Rockall bank, which had been the northern limit of the First Cruise. But as our vessel was under orders to make a Hydrographic Survey in the neighbourhood of Valentia, as soon as the scientific work of our Expedi-

* The true zoological position of this Genus, at present only known as a Carboniferous type, has lately been settled by the microscopic examination of the minute structure of the shell of specimens preserved in a *clayey* stratum of the Carboniferous series in Iowa, U.S., kindly forwarded to Dr. Carpenter by Mr. Meek, of Washington. See the Monthly Microscopical Journal for April, 1870.

† Proceedings of the Geological and Polytechnic Society of Yorkshire, 1846, p. 227.

tion should have been accomplished, we did not feel justified in interfering with that duty; since we had no reason to anticipate that such exploration would add any scientific results of importance to those we had already obtained. After coaling and refitting at Stornoway, therefore, we proceeded direct to Belfast, where we landed our collections, and took our leave of the 'Porcupine' and her highly valued Captain and Officers, with an earnest hope that we may again be brought into the same congenial companionship and hearty cooperation in future explorations of the like kind.

GENERAL RESULTS.

Physics and Chemistry.

[For this portion of the Report, Dr. Carpenter holds himself specially responsible; his Colleagues, while concurring generally in his views, being desirous of reserving their liberty to dissent from some of his conclusions.]

91. Among the most important results of the 'Lightning' Expedition was the discovery of the fact that two very different Submarine Climates exist in the deep channel (from 500 to 600 fathoms) lying E.N.E. and W.S.W. between the North of Scotland and the Faroe banks; a *minimum* temperature of 32° being registered in some parts of this channel, whilst in other parts of it, *at the same depths,* and *with the same surface-temperature* (never varying much from 52°) the *minimum* temperature registered was never lower than 46°, thus showing a difference of at least 14°. Though it could not be positively asserted that these *minima* were the *bottom*-temperatures of the Areas in which they respectively occurred, it was argued that they must almost necessarily be so: *first,* because it is highly improbable that Sea-water at 32° should overlie water at any higher temperature, which is specifically lighter than itself, unless the two strata have a motion in different directions sufficiently rapid to be recognizable; and *second,* because the nature of the Animal life found on the bottom of the Cold area exhibited a marked correspondence with its presumed depression of temperature, whilst the drift of which its Sea-bed is composed includes particles of distinctly Volcanic minerals, probably derived from a northern source, — the Sea-bed of the Warm area, on the other hand, being essentially composed of *Globigerina*-mud, and supporting a Fauna of a warmer temperate character.—This conclusion, it is obvious, would not be invalidated by any error arising from the effect of Pressure on the bulbs of the Thermometers; since, although the *actual* temperatures might be (as was then surmised) from 2° to 4° below the *recorded* temperatures, the *difference* between them would remain unaffected, the pressure exerting exactly the same influence at the same depth, whether the Soundings were taken in the Cold or in the Warm area.

92. The existence in the Cold area of a *minimum* temperature of 32°,

with a Fauna essentially Boreal, could not, it was argued, be accounted for in any other way than by the supposition of an under-current of Polar water coming down from the North or North-east; whilst, conversely, the existence in the Warm area of a *minimum* temperature of 46°, extending to 500 or 600 fathoms' depth in the Latitude of 60° (of which the normal deep-water temperature would be at least 8° less), together with the warmer temperate character of its Fauna, seemed equally indicative of a flow of Equatorial water from the South or South-west. How far this flow is part of the "Gulf-stream" proper,—that is, of the current of heated water which issues through the "Narrows" from the Gulf of Mexico,—or is attributable to some more general cause, was reserved as a matter still open to discussion; but it was urged that the existence of two such different Submarine Climates in such close proximity may be taken as an example of that continual interchange between the *Ocean-waters* of Equatorial and Polar regions, which is as much a Physical necessity as that interchange of *Air* which has so large a share in the production of winds. For the water that is cooled by the Polar atmosphere must sink and displace the water that is warmer than itself, pushing it away towards the Equator, so that in the *deepest* parts of the Ocean there will be a progressive movement in the *Equatorial* direction; whilst, conversely, the water heated by the Tropical sun, being the lighter, will spread itself north and south over the *surface* of the ocean, and will thus move towards the *Polar* regions, losing its heat as it approaches them, until it is there so much reduced in temperature as to sink to the bottom, and thence return towards its source.

93. The doctrine of the *Warm and Cold Areas,* and of the probable source of their difference, has been fully and carefully tested by the Temperature-soundings taken during the Third Cruise of the 'Porcupine;' and the result has been a complete confirmation of it in every particular; whilst an entirely new and important set of data has been afforded by the Temperature-soundings taken during the First and Second Cruises, in support of the doctrine that *a general interchange of Equatorial and Polar waters* is continually taking place in the great Oceanic basins.

94. The total number of Temperature-soundings taken during the 'Lightning' Expedition, in water of more than 100 fathoms' depth, was only 15; of which 8 were in the Warm area, and 6 in the Cold. These were all Bottom-soundings only. The total number of Stations at which Temperature-soundings were taken during the Third Cruise of the 'Porcupine,' in water of more than 100 fathoms, was 36; of these, 17 were in the Cold area, and 14 in the Warm, whilst 5 showed an intermediate range, in accordance with their border position. But besides these Bottom-soundings, *Serial* Soundings were taken at different depths in three Stations; of which No. 87 was in the Warm area, and Nos. 52 and 64 in the Cold. In the *first* of these, which was at a point about 125 miles to the N.W. of Stornoway, the temperatures were taken at 50, 100, 150,

200, 300, 400, 500, 600, and 767 fathoms (bottom) respectively, with the result of showing a reduction of only 11°·2 at the last-mentioned depth; in the *second,* which was near the S.E. border of the Faroe Bank, the temperature was taken at every 50 fathoms down to 300, and then at 384 fathoms (bottom), showing a reduction of 21°·5; while in the *third,* which was nearly midway between the Faroe and the Shetland Islands, the temperature was taken at every 50 fathoms down to 600, and then at 640 fathoms (bottom), showing a reduction of 20°·1. Of these Serial Soundings there were in all 26, making, with the 36 Bottom-soundings, a total of 62.

95. With these results, obtained with Thermometers upon which complete reliance can be placed, those obtained last year with the best ordinary Thermometers are found to be in close accordance, when the proper correction for pressure is applied to them. Thus No. 47 Sounding of the 'Porcupine' having been taken in almost exactly the same spot of the Warm area as No. XII. of the 'Lightning,'—namely, on what we now call the "*Holtenia*-ground" (§ 61),—the former gave 43°·8 as the *minimum* temperature at 542 fathoms, while the latter gave 47°·3 as the *minimum* at 530 fathoms: and the difference of 3°·5 exceeds by scarcely more than a degree—which may be a mere seasonal variation—the error (about 2°·1) which the pressure of water at that depth would produce in the unprotected thermometers. On the other hand, No. 55 Sounding of the 'Porcupine' having been taken in the same part of the Cold area as No. VIII. of the 'Lightning,'—the distance between the two being only about 8 miles,—the former gave 29°·8 as the *minimum* at 605 fathoms, while the latter gave 32° as the *minimum* at 550 fathoms; and the difference of 2°·2 is exactly equivalent to the correction for pressure at that depth in the unprotected thermometers. Thus the difference between the two 'Lightning' Soundings in the Warm and Cold areas respectively having been 15°·3, the difference between the two corresponding 'Porcupine' Soundings was 14°. This very near accordance gave us, of course, a feeling of great satisfaction in our last year's work; and it fully justified our conclusion that whatever might be the pressure-correction required by the instruments then employed, it would not affect the *differences* obtained at nearly approximating depths. It further justifies us in assuming the correctness (when thus rectified) of the *minimum* temperatures taken last year at stations considerably westward of the ground over which we worked in the 'Porcupine.'

96. The data thus obtained respecting the Temperatures at different Depths in the Warm and Cold areas respectively, are correlated in Table I., which includes, with the three sets of *Serial* Soundings, all the *Bottom*-sounding that accord with them. The localities of the several Soundings are indicated by their Numbers in Diagram III.

Table I.

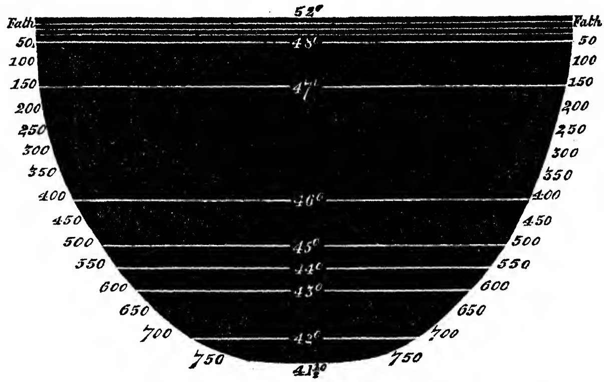
Temperature of the Sea at different Depths in the Warm and Cold Areas lying between the North of Scotland, the Shetland Isles, and the Faroe Islands; as ascertained by *Serial* and by *Bottom*-Soundings. (N.B. The Roman Numerals indicate the 'Lightning' Temperature-Soundings, corrected for pressure.)

Warm Area.							Cold Area.							
Series 87.		Station No.	Depth.	Surface Temperature.	Bottom Temperature.		Series 64.		Ser. 52.	Station No.	Depth.	Surface Temperature.	Bottom Temperature.
Depth.	Temperature.						Depth.	Temperature.	Temperature.				
fathoms.	° Fahr.		fathoms.	° Fahr.	° Fahr.		fathoms.	° Fahr.	° Fahr.		fathoms.	° Fahr.	° Fahr.
0	52·6						0	49·7	52·1				
50	48·1	73	84	52·7	48·8		50	45·5	48·5	70	66	53·4	45·2
		80	92	53·2	49·4					69	67	53·5	43·8
100	47·3						100	45·0	47·3	68	75	52·5	44·0
		71	103	53·0	48·6					61	114	50·4	45·0
		81	142	53·3	49·1					62	125	49·6	44·6
150	47·0	84	155	54·3	49·2		150	43·3	46·5	60	167	49·5	44·3
		85	190	53·9	48·7					IX.	170	52·0	41·0
200	46·8						200	39·6	45·6				
		74	203	52·5	47·7								
							250	34·3	38·4				
300	46·6						300	32·4	30·8				
										63	317	49·0	30·3
										65	345	52·0	29·9
										76	344	50·3	29·7
		50	355	52·6	46·2		350	31·4	...	54	363	52·5	31·4
		46	374	53·9	46·0		384	...	30·6				
400	46·1						400	31·0	...	86	445	53·6	30·1
		89	445	53·1	45·6		450	30·6	...				
		90	458	53·1	45·2					56	480	52·6	30·7
		49	475	53·6	45·4					53	490	52·1	30·0
500	45·1						500	30·1	...	X.	500	51·0	30·8
		XII.	530	52·5	44·8					58	540	51·5	30·8
		47	542	54·0	43·8					VIII.	550	53·0	29·8
		XV.	570	52·0	43·5		550	30·1	...	77	560	50·9	29·8
										59	580	52·7	29·7
600	43·0						600	29·9	...				
		XVII.	620	52·0	43·5					55	605	52·6	29·8
		XIV.	650	53·0	42·5					57	632	52·0	30·5
							640	29·6	...				
700													
		88	705	53·5	42·7								
767	41·4												

On examining the Series taken at Station 87 in the *Warm* area, we notice (1) that, the Surface-temperature being 52°·6, there is a fall of 4°·5 in the first 50 fathoms; (2) that from 50 to 500 fathoms there is a slow progressive and nearly uniform descent amounting in the whole to 3°, which is at the average rate of about 0°·7 per 100 fathoms; and (3) that this descent increases to 2°·1 in the next 100 fathoms, and amounts to 1°·6 in the interval of 167 fathoms between 600 fathoms and the bottom. The re-

lation between Depth and Temperature in the Warm area is represented diagrammatically in the accompanying Figure; in which (omitting fractional parts) each line marks a descent of 1° Fahr.:—

Diagram I.

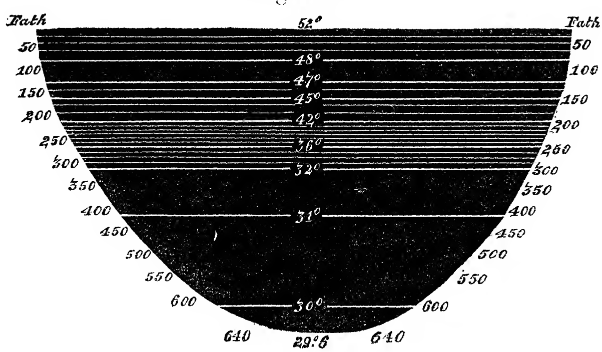


Further, on comparing this Series with the *bottom*-soundings taken in various parts of the same area, the accordance is found to be extremely close; no difference of more than a degree presenting itself anywhere, except at depths of less than 200 fathoms, the bottom-temperatures of which are higher by from 1° to 2°·2 than the temperatures at corresponding depths in the *serial* sounding. This accordance becomes at once evident when the upper curve of Diagram IV., which is constructed from twelve *bottom*-soundings in the Warm area, is compared with the upper curve in Diagram III. which represents the *serial* soundings at Station 87; while the slight difference is just what might be expected, when it is borne in mind that the superficial stratum is not here underlaid by colder water.

97. Turning from these to the Series of Temperature-soundings taken at Station 52 in the *Cold* area (distant less than 60 miles from Station 87), which begins from nearly the same surface-temperature (52°·1), we see (1) that the descent during the first 50 fathoms corresponds so closely with that observed in Series 87, that the two temperatures at that depth are almost precisely the same; (2) that at 100 fathoms the temperatures in the two series are identical; (3) that at the depths of 150 and 200 fathoms there is only a very slight difference; but that (4) whilst the reduction between 200 and 300 fathoms in the Warm area is only 0°·2, it amounts to not less than 14°·8 in the Cold area, bringing down the temperature at that depth to 30°·8; and that (5) this is further reduced to 30°·6 at the bottom of 384 fathoms.—Thus it is evident that a temperature of 32° would have been reached at somewhat less than 300 fathoms, and that the temperature of the water occupying the 100 fathoms beneath was absolutely below the freezing-point of fresh water.

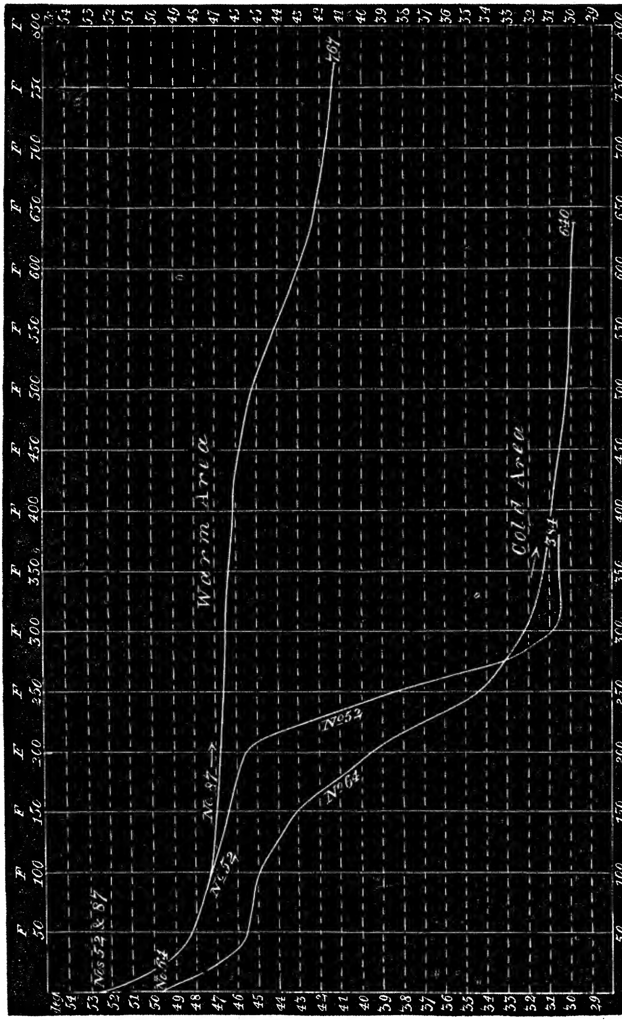
98. This result comes out even more strikingly in another Series (No. 64) taken about 180 miles to the N.E. of the preceding, in the deep channel between the Faroe and Shetland Islands. For we observe (1) that the surface-temperature is here 49°·7, or 2°·4 below that of No. 52; (2) that this difference is maintained with slight variation down to 150 fathoms; (3) that a rapid descent of the thermometer here begins, a fall of 3°·7 taking place between 150 and 200 fathoms, and a further fall of 5°·3 between 200 and 250 fathoms, making a reduction of 9° in 100 fathoms, and bringing down the temperature at 250 fathoms to 34°·3; whilst (4) the fall between 250 and 300 fathoms is only 1°·9, and between 300 and 350 fathoms is 1°, bringing down the temperature at the latter depth to 31°·4; and (5) that in descending through the lowest 290 fathoms, the temperature is reduced to 30°·1 at 500 fathoms, and stands as low as 29°·6 on the bottom at 640 fathoms. The relation between Depth and Temperature in the Cold area is represented diagrammatically in the accompanying Figure; in which, for the sake of better comparison with the preceding, the upper portion is constructed from Series 52 (so as to commence from the surface-temperature of 52°), and the lower portion from Series 64, each line marking a descent of 1° Fahr.

Diagram II.



99. Hence it is evident that a temperature of 32° would have been reached at something more than 300 (say 320) fathoms; so that the *lower half of the water occupying the deepest part of this channel forms a stream nearly* 2000 *feet in depth, having a temperature below the freezing-point of fresh water*; and this notwithstanding that the temperature of its surface and of its first 150 fathoms' depth does not differ more from the temperature of the surface and of the first 150 fathoms in the Warm area (Series 87) than is accounted for by the difference of Latitude (nearly 2°) between the two stations.—These remarkable facts are expressed by the *two lower* curves in Diagram III., which are constructed from the Serial soundings in the Cold area, as the *upper* curve is from the Serial sounding in the Warm area.

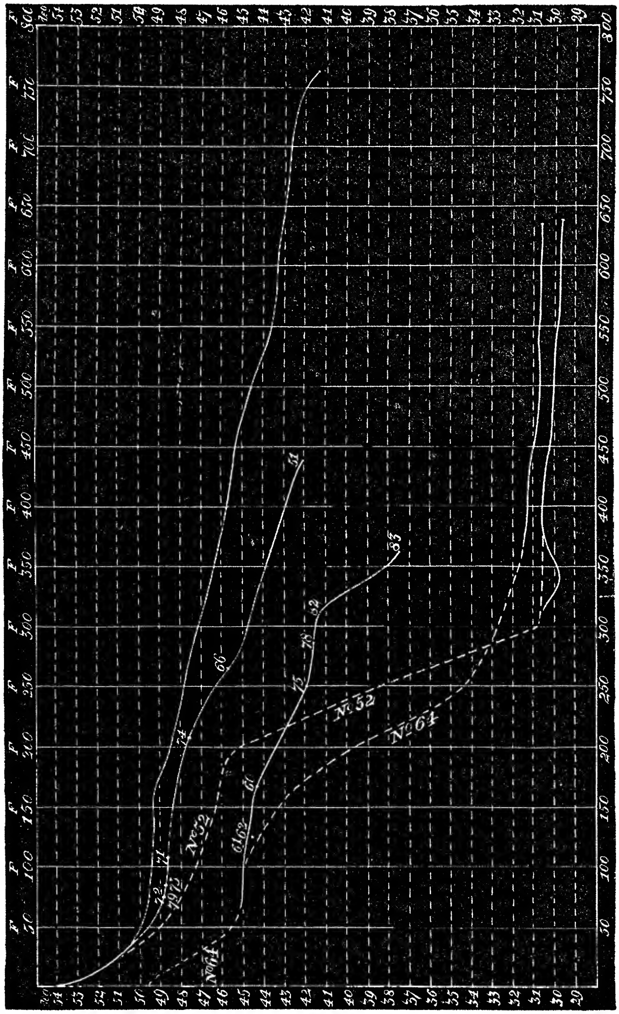
Diagram III.—Curves constructed from Serial Soundings in the Warm and Cold Areas, the Depths being represented by the *vertical* lines, and the Degrees of Fahrenheit's Thermometer by the *horizontal* lines.



100. Now on comparing these two series of Soundings with the *Bottom*-soundings taken at different parts of the Cold area, the accordance is found to be extremely close, no difference of more than a degree being found anywhere at depths greater than 300 fathoms. It is worthy of note that at the shallower depths of from 114 to 167 fathoms (Nos. 60, 61, 62), the bottom-temperatures correspond more closely to the temperatures of the same depths in Series 64 than to those of Series 52, the cold water coming nearer to the surface ; and this was still more remarkably the case with No. IX., the sounding obtained last year on a bank at 170 fathoms ('Lightning' Report, § 13). On referring to the Chart it will be found that these four stations

lie in the direct sweep of the Cold current setting from N.E. to S.W., of which Station 64 is nearly in the centre. These accordances are well exhibited in Diagram I., the two lower curves of which are constructed from

Diagram IV.—Curves constructed from Bottom-soundings in the Warm, Cold, and Intermediate Areas.



Bottom-soundings, brought into connexion with Series 52 and 64 respectively.—Two intermediate series of Bottom-soundings, of which the particulars are given in Table II., are also shown in this diagram; the peculiarities of which, when their places are sought out on the Chart, are readily accounted for. Thus Nos. 66, 71, 72, 73, 74, 75, 78, 79, 82, and 83 all lie along the S.E. bank of the deep channel between the Faroe Islands and the plateau on which the Shetland and Orkney Islands rest; and the *warm*

Table II.

Intermediate Bottom-temperatures, showing the intermixture of Warm and Cold Currents on the Borders of the Warm and Cold Areas.

Station No.	Depth.	Surface Temperature.	Bottom Temperature.	Station No.	Depth.	Surface Temperature.	Bottom Temperature.
	fathoms.	°	°		fathoms.	°	°
72	76	52·3	48·8	75	250	51·5	41·9
79	76	52·2	48·9	78	290	52·2	41·6
73	84	52·7	48·8	82	312	52·3	41·3
71	103	53·0	48·6	83	362	53·2	37·5
74	203	52·5	47·7				
66	267	52·4	45·7	51	440	51·6	42·0

surface-current that comes up from the S.W. obviously extends over that bank, so as to modify in greater or less degree, according to the depth, the effect of the deep *cold* current coming down from the N.E. The intermixture of the two is well seen in Nos. 75, 78, 82, and 83, the depths of which range from 250 to 362 fathoms; but at the shallower depths, ranging from 76 to 203 fathoms, at which Nos. 66, 71, 72, 73, 74, and 79 were taken, the influence of the *warm* surface-current is obviously predominant. On the other hand, the position of No. 51 marks it as just on the border ground between No. 50, which was taken at or near the northern margin of the *warm* current, and Nos. 52, 53, which clearly lie within the southern margin of the *cold*; and we thus see how the *southern* and *deeper* portion of the cold current may here lose itself by intermixture with the warm; whilst the northern portion seems to flow onwards unchanged over the shallower bottom, until, having passed the Faroe Banks, it runs down the slope forming the eastern margin of the great Atlantic basin, to the deeper waters of which it helps to impart the coldness by which they will presently be shown to be characterized.

101. Although we have spoken of "currents," it is not to be inferred that we have detected any actual opposing movements in the waters of the two Areas respectively, or in the warm superficial stratum of the Cold area as compared with its deep frigid layer. But it may be assumed as a physical necessity that a great body of ice-cold water could not be always spread over the bottom of a large area between Lat. $59\frac{1}{2}°$ and Lat. 62°, often to a depth of 2000 feet, unless it had arrived thither from within the Arctic circle; and, conversely, it can scarcely be conceived that the upper stratum of this very area should maintain a temperature equal to that of the Warm area (a slight allowance being made for difference of Latitude), without a continual flow of a warmer stream from some southerly quarter. —A further indication of the derivation of the deep water of the Cold Area from a northern source is afforded by the presence, among the small stones and sand brought up from this bottom, of Volcanic detritus, which seems to have been brought southwards either from the Faroe Islands or from some more remote source, such as Jan Meyen. The

presence of Volcanic detritus on that part of the floor of the channel between the Faroe Islands and Iceland which lies between its deepest point and the S.E. shore of Iceland has been already urged by Dr. Wallich *, with great force, as an argument for the existence of "an offshoot of the Arctic current slowly moving downwards" in a line about 250 miles to the westward of that which we consider ourselves to have now conclusively established; and it can scarcely be doubted that a set of Temperature-soundings taken in "the 682-fathom locality about forty miles from the southern shore of Iceland" would give Thermometric results similar to those we have obtained in the corresponding channel between the Faroe and Shetland Isles.—The import of the presence of similar Volcanic detritus on the bed of the Mid-Atlantic, as first pointed out by Prof. Bailey, will be considered hereafter (§ 117).

102. Although the thermal condition of the Warm area does not afford the like striking evidence of the derivation of its whole body of water from a Southern source, yet a careful examination of its phenomena seems fairly to justify such an inference. For it has been shown by the Serial sounding No. 87 in Lat. 59° 35′, that while the surface-water is about $4\frac{1}{2}°$ warmer than the water at 50 fathoms' depth, the latter is only 0°·8 warmer than the water at 100 fathoms; and that below this the thermometer remains almost stationary down to 400 fathoms. Now at that depth it is only 2°·4 colder than water at the same depth (Station 42) at the northern border of the Bay of Biscay, in a Latitude more than 10° to the south, where the surface-temperature was 62°·7; and the approximation of the two temperatures is yet nearer at still greater depths, the bottom-temperature at 767 fathoms at Station 87 being 41°·4, whilst the temperature at 750 fathoms' depth at Station 42 is 42°·5. So great an excess above the Isotherm of Lat. 59° 35′ can scarcely be attributed to the summer atmosphere of the locality, which we scarcely ever observed to be above 54°, and of which the effect, if exerted at all, seems limited to the "superheating" of the superficial stratum. It is obvious, again, that the surface-drift caused by the prevalence of South-westerly winds, to which some have attributed the phenomena usually assigned to the extension of the Gulf-stream to these regions, cannot account for such an elevation of temperature in a stratum altogether removed from its agency; and it seems equally difficult to conceive that in a region so remote from the source of the Gulf-stream proper, *its* influence, even if exerted in an elevation of the surface-temperature, should extend to a depth of at least 400 fathoms. It may be pretty certainly affirmed, indeed, that the effect of the warm current is exerted to the *very bottom* of the Warm area: for its temperature even at 767 fathoms is 41°·4, which is several degrees above the theoretical isotherm of the latitude; and such a temperature could scarcely be maintained at this elevation against the depressing influence of the Polar current which here mingles with it, were it not for a continual influx of warm water from a Southern source.

* North-Atlantic Sea-bed, pp. 5–7.

103. Thus the doctrine of *a general interchange between Polar and Equatorial Waters* (§ 92) seems the only hypothesis that is competent to account for the facts of this case*; and it will be found to derive further support from the Temperature-phenomena of the North-Atlantic basin, which we shall presently discuss on the basis of the Thermometric observations taken in the *First* and *Second* Cruises of the 'Porcupine,' with additional evidence from other sources.—Before proceeding to these, however, we shall inquire whether any *rationale* can be given for the special peculiarity of the Arctic current, which produces the depression of temperature to from 32°–30° everywhere noticeable at depths of from 300–640 fathoms in our Cold area.

104. A glance at the North Polar region, as laid down either on a Globe, or on any projection of which the Pole is the centre†,—as in the accompanying Chart (Plate 7) shows that the Polar Basin is so much shut-in by the northern shores of the European, Asiatic, and American Continents, that its only outlet, besides the narrow and shallow channel of Behring's Straits, and the circuitous passages leading into Hudson's and Baffin's Bays, is the space which intervenes between the eastern coast of Greenland and the north-western coast of the Scandinavian Peninsula. If, therefore, there be any such general movement of ice-cold water towards the Equatorial regions as that for which we have argued, this movement must take place mainly through the deeper portions of this interspace; at the north of which lies Spitzbergen, whilst Iceland and the Faroes lie in the middle of its southerly expanse. Now in the western portion of this channel, lying between Greenland and Iceland, the depth of water for the most part ranges from 800 fathoms to nearly double that amount; and there will here, therefore, be a free exit to the water which has been cooled down within the Arctic basin, and has consequently subsided to its deeper portions. But on the eastern side of Iceland the case is very dif-

* The existence of "Polar Currents" beneath the heated waters of Tropical regions had been indicated by various observers (see 'Lightning' Report, p. 186); but they seem to have been generally, if not universally, regarded as local peculiarities. Conversely, a movement of Equatorial water in the Polar direction, quite independent of such local accidents as those which produce the Gulf-stream proper, had been noticed in several localities; particularly between the Indian and Antarctic Oceans (see Maury's 'Physical Geography of the Sea,' §§ 748–750), where the whole movement is forced to take place towards the *South* pole, by the barrier interposed by the Continent of Asia to any flow in a *northerly* direction.—The real import of such facts as these could not be recognized by Physical Geographers, so long as they were under the "dominant idea" of a *uniform deep-sea temperature of* 39°; and our present endeavour is simply to show that the doctrine of Oceanic circulation, being at the same time in accordance with Physical theory (as laid down by Prof. Buff), and consonant with all the reliable facts yet observed, is entitled to the same rank as a fundamental principle in the science of Physical Geography, as the parallel doctrine of Atmospheric circulation holds in Meteorology.

† The ordinary Hemispherical projection of our Atlases does not give by any means a correct idea of this Polar Basin; and the Mercator's projection (which is employed by Dr. Wallich) so exaggerates the Longitude-distances in high Latitudes, as to give an entirely fallacious conception of it.

ferent. Save in the narrow channel of 682 fathoms already mentioned as existing near the S.E. of Iceland, there is no depth as great as 300 fathoms along the whole bottom as far as the Faroe Islands*; and an effectual barrier is thus interposed to any current moving southwards at a depth exceeding this. A similar barrier is presented, not merely by the plateau on which the British Islands rest, but also by the bed of the North Sea; which (as its depth nowhere exceeds 100 fathoms between the coast-line of the British Isles from Shetland to Dover on one side, and the coast-line of Norway, Denmark, and Holland from Bergen to Ostend on the other) must give to such a movement a not less effectual check than would be afforded by an actual coast-line uniting the Shetland Islands with Norway. Consequently it is obvious that a flow of ice-cold water at a depth exceeding 300 fathoms from the surface, down the north-eastern portion of this interspace, *can* only find its way southwards through the deep channel between the Faroe and Shetland Islands, which will turn it into a S.W. course, and finally discharge it into the great North-Atlantic basin, where it will meet the Icelandic and Greenland currents, and unite with them in spreading over the deepest portions of the sea-bed.

105. Hence it is obvious that if a subsidence were to take place in the area now covered by the North Sea and the British Channel, so as to depress their bottom *below* the level of that of the channel between the Faroe and Shetland Islands, the course of the Arctic current would be deflected from the latter to the former, *lowering* its bottom-temperature by at least 14°; and as the warmer current coming up from the S.W., and now ocupying our Warm area, would then meet with no check, it would extend itself over the whole of what is now our Cold area, and would *raise* its temperature at least 12°. This would have the general effect of altering almost the entire Fauna of both regions; and of modifying the characters of the deposit forming on the bottom of each.

106. *Atlantic Basin.*—During the First and Second cruises of the 'Porcupine,' the Temperature of the eastern border of the great North-Atlantic basin was examined at various depths and in widely different localities. Serial soundings were taken at no fewer than *seven* stations; the most Northerly of these being not far from Rockall Bank in Lat. 56° 8′, whilst the most Southerly was at the northern border of the Bay of Biscay, nearly 300 miles to the west of Ushant, and in Lat. 47° 38′. At Station 42 the temperature was taken at every 50 fathoms, from the surface downwards to the bottom at 862 fathoms; at Station 23 the temperature was taken at every 100 fathoms, to the bottom at 630 fathoms; and at the other Stations, at which the depths ranged from 1263 to 2090 fathoms, the Soundings were taken at every 250 fathoms.—Besides these, the *Bottom*-temperature was taken at upwards of 30 Stations, ranging in Latitude from 56° 58′ to 47° 38′, and in Depth from 54 to 2435 fathoms.—The most important of the results thus obtained are presented in Table III.

* See Dr. Wallich's 'North-Atlantic Sea-bed,' chap. i.

Table III.

Temperature of the Sea at different Depths near the Western margin of the North-Atlantic Basin, as ascertained by *Serial* and by *Bottom*-Soundings.

Serial Soundings.

Depth.	Temperature. Ser. 23.	Temperature. Ser. 42.	Temperature. Ser. 22.	Temperature. Ser. 19.	Temperature. Ser. 20.	Temperature. Ser. 21.	Temperature. Ser. 38.
fathoms.	° Fahr.	° Fahr.	° Fahr.	° Fahr.	° Fahr.	° Fahr.	° Fahr.
0	57·3	62·6	56·9	54·8	55·5	56·2	64·0
50	...	53·2					
100	48·5	51·1					
150	...	50·9					
200	48·0	50·5					
250	...	50·2	48·5	48·0	48·5	48·3	50·5
300	47·8	49·6					
350	...	49·1					
400	47·5	48·5					
450	...	47·6					
500	45·8	47·4	46·7	46·7	46·9	47·5	47·8
550	...	46·4					
600	44·5	45·5					
630	43·4						
650	...	44·3					
700	...	43·6					
750	...	42·5	42·0	41·2	41·6	42·4	41·3
800	...	42·0					
862	...	39·7					
1000	...	...	38·8	38·5	38·8	38·5	38·3
1263	...	...	37·3				
1250	...	...	...	...	37·7	37·9	37·7
1300							
1360	...	...	...	37·4			
1400							
1443	...	...	...	...	37·0		
1476	...	...	...	...	...	36·9	
1500	...	...	...	...	...	...	37·2
1750	...	...	...	...	...	...	36·7
2090	...	...	...	...	...	...	36·3

Bottom-Soundings.

Station No.	Depth.	Surface Temperature.	Bottom Temperature.
	fathoms.	° Fahr.	° Fahr.
27	54	55·6	48·3
34	75	66·0	49·7
6	90	54·0	50·0
35	96	63·4	51·3
8	106	54·2	51·2
24	109	57·7	46·5
7	159	53·2	50·4
14	173	53·2	49·6
18	183	53·2	49·4
13	208	53·6	49·6
4	251	53·5	49·5
26	345	57·4	46·7
1	370	54·0	49·0
15	422	52·2	47·0
45	458	60·7	48·1
40	517	63·4	47·7
39	557	63·0	47·0
41	584	63·4	46·5
23 *b*	664	57·4	41·6
12	670	52·2	42·6
3	723	54·5	43·0
36	725	63·9	43·9
2	808	54·1	41·4
16	816	53·0	39·5
44	865	61·2	39·4
43	1207	61·7	37·7
28	1215	57·7	37·1
17	1230	53·2	37·8
29	1264	56·9	36·9
32	1320	55·9	37·4
30	1380	56·0	37·1
37	2435	65·6	36·5

107. Amongst all these the coincidence of Temperatures at corresponding Depths is extraordinarily close; the chief differences show themselves, as might be expected, in Surface-temperature. This was peculiarly high in the most Southerly stations, which lay between Lat. 47° and 49° 51′, rising to 62°·6 at Station 42, to 64°·8 at Station 38, to 65°·6 at Station

37 (which was that of the 2435 fathoms' dredging), and to 66° at Station 34: whilst it fell in the more Northerly Stations, which lay between Lat. 53° 41′ and 54° 53′, to 54°·8 at Station 19, to 53°·2 at Stations 17 and 18, though these were rather to the southward of the preceding, and to 52°·2 at Station 12, which was yet further south. A comparison of the temperature of the Surface-water with that of the Air at each Station indicates that a large part of the variation in the former is due, on the one hand, to the heating effect of the solar rays, and on the other to the cooling influence of winds. Thus at three Stations at which the Surface-temperatures were 64°·8, 65°·6, and 66° respectively, the thermometers in Air showed 63°·5, 70°, and 72°; whilst at four Stations at which the Surface-temperatures ranged downwards from 54°·8 to 52°·2, the temperature of the Air ranged from 55°·5 to 53°. In only one instance was the temperature of the Air decidedly lower than that of the Surface-water; and this was at Station 42, where, although the Surface-temperature was 62°·6, the temperature of the Air was only 59°. But as this observation was made at 4^h 30^m on the morning of July 27, and as the wind was from the N.W., the discrepancy may be regarded as accidental.

108. At the last-mentioned Station, in Lat. 49° 12′, about 250 miles to the S.W. of Cork, a Series of Temperature-soundings was taken at every 10 fathoms from the surface to 50 fathoms, with the view of determining the rate of thermal decrease at successive depths in the superficial stratum. The total decrease in this descent amounted to 9°·4; the most rapid diminution being between 20 and 30 fathoms, within which vertical space the reduction amounted to 3°·4. In the next 10 fathoms it was only 1°·6, and in the 10 following only 1°·2. Between 50 and 100 fathoms the total reduction was only 2°·1; and it may be fairly surmised that a large part of this occurred in the upper 20 fathoms; for below 100 fathoms the rate of diminution becomes extremely slow, the total reduction between 100 and 500 fathoms being only 3°·7, or at an average of 0·9 per 100 fathoms. The rate of diminution then again becomes more rapid, the total reduction between 500 and 800 fathoms being 5°·4, or 1°·8 per 100 fathoms; and between 800 and 862 fathoms (bottom) there is a still more rapid diminution, a reduction of 2°·3 taking place in this comparatively small descent.

109. On comparing with this the Series taken at every 100 fathoms at Station 23, in Lat. 56° 13′, we see a very close general accordance in the rate of descent; although the actual temperatures of the latter are from 2° to 3° lower than those of the former at corresponding depths, as might be expected from its higher Latitude. In the Surface-temperature, indeed, the difference amounts to 5°·3; but this becomes reduced to 2°·6 at 100 fathoms, to 2°·5 at 200 fathoms, to 1°·8 at 300 fathoms, and to 1°·0 at 400 and 600 fathoms. The total reduction in the first 100 fathoms is here 8°·8, as against 11°·5 in the preceding case; while the reduction between 100 and 500 is also rather less, being 2°·7.

110. Extending the comparison to a Series taken still further northwards,

namely at Station 87 in Lat. 59° 35′ (more than 10° to the north of Station 42), the same general accordance presents itself in the rate of descent; while the actual temperatures at the several depths below 100 fathoms are by no means as different as might be expected from the difference in the geographical position of the Stations, as will be apparent from the following Table:—

Table IV.

Comparative Rates of Reduction of Temperature with Increase of Depth, at three Stations in different Latitudes, all of them on the Eastern Margin of the Atlantic Basin.

Depth.	Station 42. Lat. 49° 12′.		Station 23. Lat. 56° 13′.		Station 87. Lat. 59° 35′.	
	Temperature.	Difference.	Temperature.	Difference.	Temperature.	Difference.
fathoms. Surface	62°·6		57°·3		52°·5	
		11°·5		8°·8		5°·2
100......	51·1		48·5		47·3	
		0·6		0·5		0·5
200......	50·5		48·0		46·8	
		0·9		0·2		0·2
300......	49·6		47·8		46·6	
		1·1		0·3		0·5
400......	48·5		47·5		46·1	
		1·8		1·7		1·0
500......	46·7		45·8		45·1	
		1·2		1·3		2·1
600......	45·5		44·5	......	43·0	
		3·0				
750......	42·5	......	......	......	......	1·6
767......	......	......	......	......	41·4	

Although the difference between the Surface-temperatures at Stations 42 and 87 amounts to 10°·1, the difference is reduced to 3°·8 at 100 fathoms, to 3° at 300 fathoms, to 2°·5 at 600 fathoms, and to 1°·1 at 750 fathoms. So, again, the reduction in the first 100 fathoms at Station 87 being only 5°·2, the total reduction between 100 and 500 fathoms is only 2°·2, or at the rate of 0°·55 per 100 fathoms. But the rate of depression then undergoes nearly as marked an increase as at the corresponding depth in Station 42; for whilst the diminution of temperature between 500 and 750 fathoms amounts at Station 42 to 4°·2, or 1°·7 per 100 fathoms, it amounts at Station 87 to 3°·7, or 1°·5 per 100 fathoms.

111. It becomes obvious, therefore, in the *first* place, that there is a decided *superheating* of the superficial stratum, not extending to a depth much greater than 70 or 80 fathoms, and that this is more considerable (as might be expected) at the Southern than at the Northern stations. Whether this "superheating" is entirely due to the direct influence of solar heat, or depends in any degree (especially in the southern portion of this area) on an

extension of the Gulf-stream, is a question which can only be resolved by the determination of its relative amount in summer and in winter; and as this solution could be very easily obtained (sets of Temperature-soundings at every 10 fathoms down to 100 fathoms, taken in these opposite periods of the year, being all that is requisite), it may be hoped that the cause of this "superheating" will not long remain undetermined.

112. With regard, *secondly*, to the Temperature of the 400 fathoms beneath the superficial 100, which ranges between 51°·1 and 46°·7 in Lat. 49° 12′, between 48°·5 and 45°·8 in Lat. 56° 13′, and between 47°·3 and 45°·1 in Lat. 59° 35′, it may be pretty certainly affirmed that whilst it is somewhat higher than the Isotherm of the Southern station, it is so considerably above that of the Isotherms of the Northern stations, as decidedly to indicate that the body of water between these depths has found its way thither from a Southern source (see § 102).

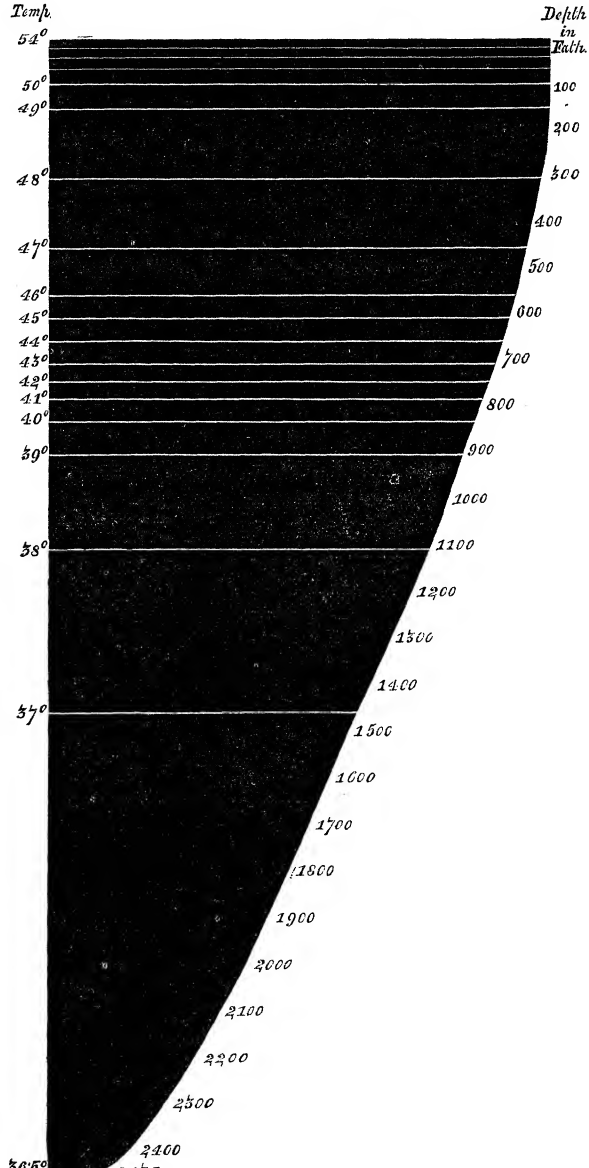
113. Proceeding, *thirdly*, to the still greater depths of which the Temperatures are recorded in Series 22 (1263 fath.), Ser. 19 (1360 fath.), Ser. 20 (1443 fath.), Ser. 21 (1476 fath.), and Ser. 38 (2090 fath.), all which are in remarkably close accordance with each other, we meet with a decided change in the rate of decrease of temperature at equal intervals of depth; for whilst the average of the whole five gives a reduction of no more than 1°·6 between 250 and 500 fathoms (that is, 0°·6 per 100 fathoms), the reduction between 500 and 750 fathoms is 5°·4, or at the rate of 2°·1 per 100 fathoms; while between 750 and 1000 fathoms it amounts to 3°·1, bringing down the temperature at the latter depth to an average of 38°·6. Though the rate of diminution of temperature then becomes slower, there is still a progressive decrease of temperature with increase of depth, the total reduction between 1000 and 2090 fathoms being just 2°, so as to bring down the temperature at the latter depth to 36°·3.

114. With these Series the numerous *Bottom*-temperatures taken in the First and Second Cruises, and tabulated in Table III., are for the most part in remarkably close accordance. This accordance is greatest at depths between 1000 and 2435 fathoms; the temperature at the last-mentioned depth showing no reduction* below that of the 2090 fathoms' sounding. The accordance between the Serial and the Bottom-soundings is not so constant, however, at smaller depths; the temperature of the *bottom* being in several instances from two to four degrees lower than that of the corresponding stratum in the serial soundings. Thus in No. 24, at a depth of only 109 fathoms, the bottom-temperature was 46°·5, or 4° below the ordinary temperature at that depth. In No. 26, at a depth of 345 fathoms, the bottom temperature was 46°·7; at least 2° below the average. In No. 23 *b*, at 664 fathoms, the bottom-temperature was 41°·6, and in No. 12, at 670 fathoms, the bottom-temperature was 42°·6, being in the one case about $2\frac{1}{2}$° and in the other about $1\frac{1}{2}$° below what might have been expected at those depths. These differences suggest the hypothesis that variations in

* Its apparent *excess* of 0°·2 is quite within the limit of error of observation.

the contour of the sea-bed may bring an admixture of frigid water nearer to the surface in particular localities than in the basin generally.

Diagram V.



115. The general results obtained by the correlation of all these data are represented diagrammatically in Diagram V., which, being constructed upon

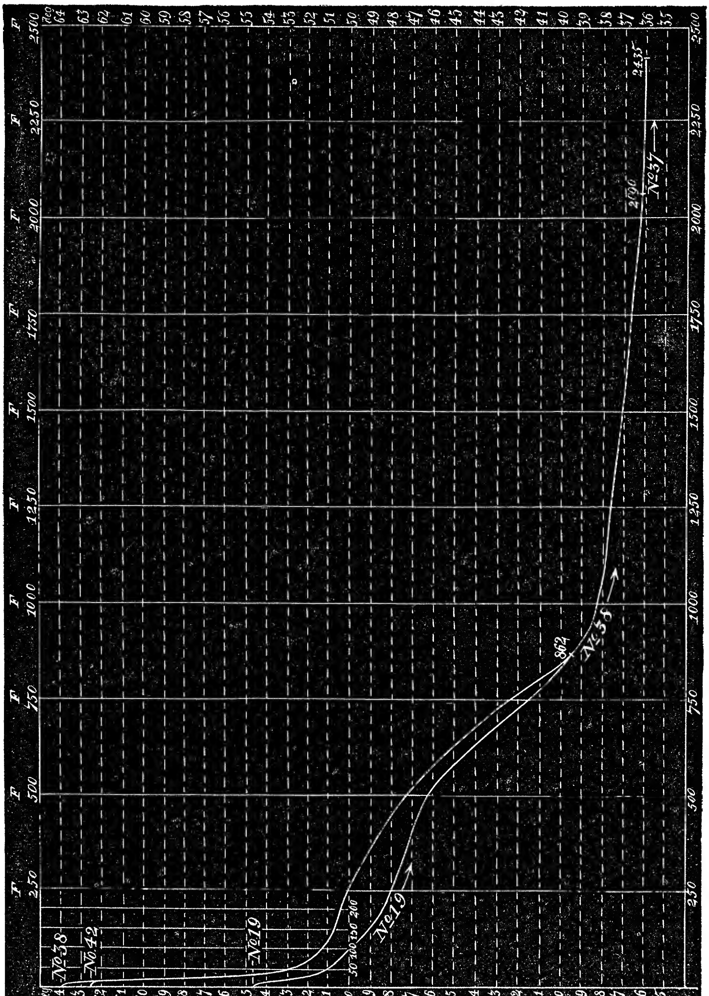
the same scale as the two preceding figures of the same kind (pp. 457, 458) enables the relation between Depth and Temperature in the Atlantic Basin to be compared with the like relation in the Warm and Cold Areas respectively. For the sake of convenience, the Surface-temperature is here taken at 54°, this (as shown in Table III.) having been its average at those Stations in which the "superheating" did not conspicuously manifest itself.

116. When the rates of decrease of Temperature in successive strata of this deep Atlantic Basin are compared with those which have been shown to exist in the thinner strata of our comparatively shallow Cold area, a very remarkable relation presents itself, the Thermometric changes requiring in the former case a much greater Bathymetric descent than in the latter, but corresponding very closely with them when this allowance is made. This relation may be presented to the mind by ideally extending Diagram II. in a vertical direction, so that its horizontal lines should be separated by four times their interval. It has been shown (§ 98) that in the latter the stratum of about 100 fathoms which lies below the superficial 50 shows but a very slight decrease of temperature, presenting almost exactly the same rate of descent as the stratum between similar depths in the neighbouring Warm area. Now with this 100 fathoms' stratum, a stratum of about 500 fathoms beneath the superficial 100 in the deep Atlantic very closely corresponds, the reduction down to 500 fathoms being at an extremely slow rate. Between 150 and 300 fathoms in the Cold area, however, the rate of reduction becomes very much greater; and this is just what presents itself in the Atlantic Basin between 500 and 1000 fathoms; so that as in the Cold area we come down at very little below 300 fathoms upon a stratum of ice-cold water, so in the Atlantic basin we come down at 1000 fathoms upon a stratum averaging 38°·6. And further, as there is below this a slow progressive diminution of about 2° as we descend through the lower 300 fathoms of the Cold area, so a like progressive diminution is shown as we descend through the lower 1000 fathoms of the deep Atlantic Basin.

117. The significance of these facts becomes yet more apparent, when the varying rates of diminution of temperature in successive strata of the deep Atlantic Basin are reduced to a curve (Diagram VI.), in the same manner as the corresponding rates in successive strata of the Cold area; but with a reduction in the scale of depths in the former case, so as to make 500 fathoms in the deep basin correspond with 150 in the comparatively shallow channel. It is true that there is by no means the same *absolute* reduction in the one case as in the other; but this difference is just what would be anticipated on the hypothesis we have been advocating. For if it be supposed that the body of ice-cold water brought down from the Arctic basin by the various Polar currents is discharged into the wide and deep Atlantic Basin, it will tend to diffuse itself over its bottom, partly displacing and partly mingling with the water which previously occupied it, so as to form a stratum of considerable thickness, which, while much colder than the

water nearer the surface, has lost the extreme frigidity which characterizes the current at a comparatively small depth when it comes fresh from the Arctic basin. And just as the rapid descent of temperature between 150

Diagram VI.—Curves constructed from Serial Soundings in the Atlantic Basin.



and 300 fathoms in the Cold area may be taken to indicate that this is the ***stratum of intermixture*** between the warm superficial stream coming from the Southward and the deep flow of ice-cold water coming from the Northward, so may the like rapid diminution between 500 and 1000 fathoms in the Atlantic basin be taken as indicating that this is the ***stratum of intermixture*** between the great body of surface-water carrying a higher temperature from the Equatorial towards the Polar regions, and the diluted

Polar stream which seems to occupy all the deeper parts of the basin to within about 1000 fathoms of the surface, and thus carries back Polar water to the Equatorial area.

118. These inferences are fully borne out by the Temperature-soundings recently taken by Commander Chimmo, R.N., and Lieut. Johnson, R.N., at various points of the North-Atlantic Basin; for although the temperatures of these Soundings were recorded by unprotected Thermometers, yet the error to which the best of those instruments are subject from the effects of pressure at different depths can now be estimated, and the requisite correction applied to each observation, so as pretty certainly to give the true temperature in each case within a degree. These Soundings give a temperature of about 39° at 1000 fathoms, which is almost exactly accordant with the average of our own; but the "stratum of intermixture," indicated by the rapid reduction of temperature with increase of depth, seems to lie rather nearer the surface, the rapid reduction commencing at about 400 fathoms instead of at about 500. Below 1000 fathoms, at depths progressively increasing to 2270 fathoms, the temperatures are in extraordinarily close accordance with our own, the *minimum*, however, apparently falling a little lower. Thus at 2270 fathoms, the temperature recorded by an unprotected Casella thermometer was 44°; but the estimated correction for the instrument at that depth being 9°, the real temperature would be 35°.

119. It has thus been shown that the hypothesis advanced in our preceding Report, when worked out in connexion with the peculiar Geographical relations of the Arctic to the North-Atlantic basin, goes far to account for the two orders of phenomena which have now been examined, namely:—

(I.) The movement of a vast body of *warm* water, extending to a depth of several hundred fathoms, in a north-east direction, which moderates the cold of the Boreal area by bringing into it the warmth of that vast expanse of the North-Atlantic Ocean which is heated beneath the Tropical sun.

(II.) The existence of a flow of *ice-cold* water, at depths greater than 300 fathoms, in a south-west direction along the floor of the channel between the North of Scotland and the Faroe Islands, which contributes, with other frigid streams from the Arctic basin, to diffuse over the North-Atlantic sea-bed, at depths greater than 1000 fathoms, a Temperature below 39°, ranging downwards with increase of depth to about 35°.

And it further appears:—

(III.) That the "Gulf-stream" may be regarded as a kind of intensification of the ordinary flow of Surface-water from the Equatorial to the Polar area, this intensification being due to the peculiar local conditions which produce an extraordinary "superheating" of water in the Gulf of Mexico, and the diffusion of this superheated water thence over a vast proportion of the North-Atlantic area, raising its Surface-temperature by several degrees.

(IV.) That the Frigid stream which imparts to our Cold area, in the latitude of the Shetland Islands, a Bottom-temperature below 30°, may in like manner be considered as an intensification of the ordinary flow of deep water from the Polar to the Equatorial area, this intensification being due to the peculiar local conditions which limit the flow into the Atlantic basin of the water that has been cooled in the Polar basin, and thus keep it from intermixture with warmer water, whilst, by the narrowing of its channel, it is forced up nearer to the surface.

(V.) That as the temperature of the Gulf-stream is reduced, and the depth of its stratum diminished, the further it diffuses itself over the surface-water of the Atlantic, so the temperature of the Frigid Stream is raised by admixture with the warmer water through which it diffuses itself in the Atlantic basin, whilst it descends deeper and deeper beneath the surface with the increasing depth of the floor on which it rests.

120. It may be questioned, however, whether the low temperature thus shown to prevail, not only over the deepest portion of the North-Atlantic sea-bed, but throughout the enormous mass of water which lies below the "stratum of intermixture" (§ 117), is attributable solely, or even principally, to the cooling effect of the comparatively small quantity of frigid water discharged from the Arctic basin into this vast area, through the narrow channels previously indicated (§ 104). For it is to be remembered that the converse heating-action exerted by the solar rays over the southern portion is continually pumping up this cold water (so to speak) from the depths to the surface; and that this movement will be aided from below by the heat continually imparted from the solid ocean-bed to the colder water which rests upon it. Now as the most trustworthy observations on Deep-sea Temperatures under the Equator, though few in number *, indicate that even there a temperature not much above 32° prevails, it seems probable that part of the cooling effect is due to the extension of a flow of frigid water from the *Antarctic* area, even to the north of the Tropic of Cancer. It seems impossible to give any other explanation of the low temperatures observed in the 'Hydra' soundings across the Arabian Gulf †, since no frigid water from the Arctic basin could be supposed to find its way to that locality.

121. The unrestricted communication which exists between the *Antarctic* area and the great *Southern* Ocean-basins would involve, if the doctrine of a general Oceanic circulation be admitted, (1) a much more considerable interchange of waters between the Atlantic and the Equatorial areas than is possible in the Northern hemisphere; and (2) a reduction in the tem-

* See 'Lightning' Report, p. 186.

† 'Lightning' Report, p. 187, note:—The lowest Temperature *actually observed* in these Soundings, with Thermometers protected on Admiral Fitzroy's plan, was $36\frac{1}{2}$°. The temperature of $33\frac{1}{2}$° given in the 'Lightning' Report as existing below 1800 fathoms, proves to have been only an *estimate* formed by Captain Shortland, under the idea that the rate of reduction observed at smaller depths would continue uniform to the bottom, which the Serial soundings of the 'Porcupine' prove to be by no means the case.

perature of the deepest parts of the great Southern Ocean even below that of the North-Atlantic Sea-bed. Now so far as our present knowledge extends, both these inferences are in accordance with fact; for it is well known to Navigators that in all the Southern Oceans there is a perceptible "set" of warm surface-water towards the Antarctic Pole (this "set" being so decided in one part of the Southern Indian Ocean as to be compared by Capt. Maury to the Gulf-stream of the North Atlantic); and it is obvious that such a constant flow of surface-water cannot be maintained without an equivalent flow of deeper water in the opposite direction. Of the great depression of temperature which would be produced by such an unrestricted spread of frigid water over the deeper parts of the Southern Oceanic basins, indications are afforded by the deep Temperature-soundings taken in Sir James C. Ross's Antarctic Expedition, the Voyage of the 'Venus,' &c.; for when, as in several of these observations, the *indicated* Temperature was from 39° to 36° at depths greater than 1500 fathoms, the probable correction for pressure would reduce these to *actual* temperatures of from 32° to 29°, or even lower.

122. It would appear from the foregoing considerations that the Temperature of the Deep Ocean will everywhere depend upon the amount of Frigid water which can find its way from the Polar towards the Equatorial area; and that this will be mainly regulated by the Distribution of Land and Water, any considerable alteration in which may produce a wide-spread general change of submarine climate over vast areas, besides modifying, in the manner already pointed out (§ 105), the distribution of submarine climate over the parts of the Sea-bed traversed by special Polar or Equatorial Polar currents. And thus great additional force is added to the remark made in the 'Lightning' Report (p. 194) that a considerable modification of Submarine Climate might depend upon alterations in the contour of the land, or on the level of the sea-bottom, *at a great distance.* For when the South Polar basin was in great part shut in by the Antarctic Continent which (as appears from Dr. Hooker's Botanical researches) must have formerly united South America, New Zealand, and Australia, the Deep-sea temperature of the Southern Oceanic area generally must have been *higher* by some degrees than we have reason to believe it to be at present; whilst, on the other hand, if there ever was a time when the present North Pacific Area had a more free communication with the Arctic Basin than the present narrow and shallow channel of Behring's Straits affords, its Deep-sea temperature must have been *lower* by some degrees than it is likely to be found at present.

123. It is obvious that the distribution of Submarine Climate must exert a most important influence on the distribution of Animal Life; and of such influence the Deep-sea Dredgings carried on in this Expedition through a wide Geographical range have afforded most convincing evidence; as will be fully set forth in the Second Part of this Report. For many species of Mollusca, Crustacea, and Echinodermata previously supposed to

to be purely Arctic have been found to range southwards in deep water as far as those dredgings extended—namely, to the northern extremity of the Bay of Biscay; and the considerations already urged render it highly probable that an extension of the same mode of exploration would bring them up from the abysses of even Intertropical seas, over which a similar Climate prevails, and that an actual continuity may thus be found to exist between the Arctic and the Antarctic Faunæ. This idea was well put forth some years since by our excellent friend Prof. Lovén of Stockholm, in his discussion of the results of the deep-sea Dredgings executed by the Swedish Spitzbergen Expedition of 1861, under Torell. "Considering," he says, "the power of endurance in these lower marine animals, and recollecting the facts that properly Arctic species which live also on the coast of Europe, are generally found there at greater depths than in their proper home, and that certain Antarctic species very closely agree with Arctic species, the idea occurs that, while in our own seas and those of warm climates, the surface, the coast-line, and the lesser depths are peopled with a rich and varied Fauna, there exists in the great Atlantic depression, perhaps in all the abysses of our globe, and continued from Pole to Pole, a Fauna of the same general character, thriving under severe conditions, and approaching the surface where none but such exist, in the coldest seas." It had, moreover, been long previously suggested by Sir James C. Ross, on the basis of observations made during his Antarctic voyage; for these observations had led him to believe that water of similar temperature to that of the Arctic and Antarctic seas exists in the depths of the Equatorial Ocean, and that Arctic species may thus find their way to the Antarctic area, and *vice versâ*.—The "similar temperature" believed by Sir James Ross to have had this general prevalence seems to have been 39°; whereas our observations distinctly prove that a temperature even below 30° may be conveyed by Polar streams far into the Temperate zone, and that the general temperature of the deepest part of the North-Atlantic sea-bed has more of a Polar character than he supposed. Further, as there must have been deep seas at all Geological epochs, and as the Physical forces which maintain the Oceanic circulation must have been in operation throughout, though modified in their local action by the particular distribution of land and water at each period, it is obvious that the presence of Arctic types of animal life in any Marine formation can no longer be accepted as furnishing evidence *per se* of the general extension of Glacial action into Temperate or Tropical regions.

124. Whilst the question of Deep-Sea Temperature is one of the greatest Biological interest, its determination is of even greater importance to the Geologist, as affecting his interpretation of the phenomena on which his belief in a former general prevalence of a Glacial climate is founded. For if a Glacial temperature should be found now to prevail, and types of Animal life conformable thereto should prove to be diffused, over the deeper portion of the existing sea-bed in all parts of the Globe, it is obvious that the same

may have been the case at *any* Geological epoch; for there must have been deep seas in all periods, and the Physical forces which maintain the Oceanic circulation at the present time must have been *always* in operation, though modified in their local action by the distribution of land and water existing at any particular date. And as the elevation of the present deep sea-bed of even the intertropical Oceanic area would (if we have correctly interpreted the results of our own and others' observations) offer to the study of the Geologist of the future a deposit characterized by the presence of Polar types, so must the Geologist of the present hesitate in regarding the occurrence of Boreal types in any marine deposit as adequate evidence *per se* of the general extension of Glacial action into Temperate or Tropical regions. At any rate, it may be considered as having been now placed beyond reasonable doubt that *a Glacial Submarine Climate may prevail over any Area, without having any relation whatever to the Terrestrial Climate of that Area* *.

125. *Composition of Sea-Water.*—A considerable number of samples of Sea-water were collected in different localities and at different depths, for the purpose of being submitted, on our return home, to the complete analysis which Dr. Frankland had been kind enough to undertake. As the quantities collected in the first two cruises, however, proved insufficient for his special purpose—the determination of the quantity of Organic matter,—a set of Winchester quart bottles was taken out in the Third cruise; and these were filled from *surface-* and from *bottom*-waters in four localities, two in the Warm and two in the Cold area. The important results of Dr. Frankland's analyses of these samples are given in Appendix II. The differences in *Specific Gravity,* and in the proportion of the ordinary *Saline* constituents (as indicated by that of the chlorine) are scarcely as great as might have been anticipated; but in so far as they extend, they are generally conformable to the doctrine of Forchammer, that Polar water is more dilute than Equatorial. In particular it may be noted that the lowest Specific Gravity (1·0262), which coincided with a still lower proportion in the total of Solid matter, presented itself in the waters taken from the Arctic stream nearest its presumed source (§ 70). But the most novel and important feature in these analyses is the large quantity of *Organic Matter* indicated by them as universally present in the water of the open Ocean at great distances from land and at all depths. This has a direct bearing on a question of the greatest Biological interest,—What is the *source of Nutriment* for the vast mass of Animal life covering the abyssal Sea-bed?

126. That Animals have no power of themselves generating the Organic Compounds which serve as the materials of their bodies—and that the production of these materials from the carbonic acid, water, and ammonia

* Since the above was written, we have learned from Prof. Liveing, of Cambridge, that Mr. Lucas Barrett, formerly Assistant to Prof. Sedgwick, ascertained, not long before his lamented death, the existence of a temperature not far above the freezing-point in the deepest part of the sea near Jamaica.

of the Inorganic world, under the influence of Light, is the special attribute of Vegetation—is a doctrine so generally accepted, that to call it in question would be esteemed a Physiological heresy. There is no difficulty in accounting for the alimentation of the higher Animal types, with such an unlimited supply of food as is afforded by the *Globigerinæ* and the *Sponges* in the midst of which they live, and on which many of them are known to feed. Given the *Protozoa*, everything else is explicable. But the question returns,—On what do these *Protozoa* live?

127. The hypothesis has been advanced that the food of the abyssal *Protozoa* is derived from *Diatoms* and other forms of minute Plants, which, ordinarily living at or near the surface, may, by subsiding to the depths, carry down to the animals of the sea-bed the supplies they require. Our examination of the surface-waters, however, has afforded no evidence of the existence of such Microphytic vegetation in quantity at all sufficient to supply the vast demand; and the most careful search in the *Globigerina*-mud has failed to bring to light more than a very small number of specimens of these Siliceous envelopes of Diatoms, which would most assuredly have revealed themselves in abundance had these Protophytes served as a principal component of the food of the *Protozoa* that have their dwelling-place on the sea-bed.—Another hypothesis has been suggested, that these *Protozoa*, which are so near the border of the Vegetable kingdom, may be able, like Plants, to generate Organic Compounds for themselves,—manufacturing their own food, so to speak, from Inorganic materials. But it is scarcely conceivable that they could do this without the agency of Light; and, as it is obviously the want of that agency which excludes the possibility of Vegetation in the abysses of the ocean, the same deficiency would prevent Animals from carrying on the like process.

128. A possible solution of this difficulty, first offered by Professor Wyville Thomson in a Lecture delivered in the spring of 1869, has received so remarkable a confirmation from the researches made in the 'Porcupine' expedition, that it may now be put forth with considerable confidence. It is, he remarked, the distinctive character of the *Protozoa*, that "they have no special organs of nutrition, but that they absorb water through the whole surface of their jelly-like bodies. Most of these animals secrete exquisitely formed skeletons, sometimes of Lime, sometimes of Silica. There is no doubt that they extract both of these substances from the Sea-water, although Silica often exists there in quantity so small as to elude detection by chemical tests. All Sea-water contains a certain amount of Organic matter in solution. Its sources are obvious. All rivers contain a large quantity; every shore is surrounded by a fringe, which averages about a mile in width, of olive and red Seaweeds; in the middle of the Atlantic there is a marine meadow, the Sargasso Sea, extending over 3,000,000 of square miles; the sea is full of Animals which are constantly dying and decaying; and the water of the Gulf-stream especially courses round coasts where the supply of organic matter is enormous. It is, therefore, quite

intelligible that a world of animals should live in these dark abysses: but it is a necessary condition that they should chiefly belong to a class capable of being supported by absorption through the surface of matter in solution, developing but little heat, and incurring a very small amount of waste by any manifestation of vital activity. According to this view, it seems highly probable that at all periods of the earth's history some form of the Protozoa (Rhizopods, Sponges, or both) predominated over all other forms of animal life in the depths of the Sea, whether spreading, compact, and reef-like, as in the Laurentian and Palæozoic *Eozoon*, or in the form of myriads of separate organisms, as in the *Globigerinæ* and *Ventriculites* of the Chalk "*.

129. During each Cruise of the 'Porcupine,' samples of Sea-water obtained from various depths, as well as from the surface, at stations far removed from land, were submitted to the Permanganate test after the method of Prof. W. A. Miller, with an addition suggested by Dr. Angus Smith for the purpose of distinguishing the Organic matter *in a state of decomposition* from that which is only *decomposable*; with the result of showing the uniform presence of an appreciable quantity of matter of the latter kind, which, not having passed into a state of decomposition, may be assimilable as food by animals,—being, in fact, Protoplasm in a state of extreme dilution. —Until, therefore, any other more probable hypothesis shall have been proposed, the sustenance of Animal life on the ocean-bottom at any depth may be fairly accounted for on the supposition of Prof. Wyville Thomson, that the Protozoic portion of that Fauna is nourished by direct absorption from the dilute Protoplasm diffused through the whole mass of Oceanic waters, just as it draws from the same mass the Mineral ingredients of the skeletons it forms. This diffused Protoplasm, however, must be continually undergoing decomposition, and must be as continually renewed; and the source of that renewal must lie in the *surface-life* of Plants and Animals, by which (as pointed out by Prof. Wyville Thomson) fresh supplies of Organic matter must be continually imparted to the Oceanic waters, being carried down even to their greatest depths by that *liquid diffusion* which was so admirably investigated by the late Professor Graham.

130. The analysis of the *Gases* contained in Sea-water, collected not only at the surface but from various depths beneath it, was systematically carried on during the whole of the Expedition. The results cannot be considered as entirely satisfactory; since it is by no means certain that the relative proportions of the gases obtained by boiling water taken up from great depths may not have been affected by the liberation of a portion of these gases when the superincumbent pressure was removed. But they will be found extremely suggestive, and seem to have a tolerably definite relation to the *Respiration* of the Abyssal Fauna. Referring to Appendix I. for a fuller statement of details, we may here call attention to their general

* "The Depths of the Sea," a Lecture delivered in the theatre of the Royal Dublin Society, April 10, 1869.

bearing.—The general average of thirty analyses of *surface*-water gives the following as the percentage proportions:—25·1 Oxygen, 54·2 Nitrogen, 20·7 Carbonic Acid. This proportion, however, was subject to great variations, as will be presently shown. As a general rule, the proportion of Oxygen was found to diminish, and that of Carbonic Acid to increase, with the depth, the results of analyses of *intermediate* waters giving a percentage of 22·0 Oxygen, 52·8 Nitrogen, and 26·2 Carbonic Acid; whilst the results of analyses of *bottom*-waters gave 19·5 Oxygen, 52·6 Nitrogen, and 27·9 Carbonic Acid. But *bottom*-water at a comparatively small depth often contained as much Carbonic Acid and as little Oxygen as *intermediate* water at much greater depths; and the proportion of Carbonic Acid to Oxygen in *bottom*-water was found to bear a much closer relation to the abundance of Animal life (especially of the more elevated types), as shown by the Dredge, than to its depth. This was very strikingly shown in an instance in which analyses were made of the gases contained in samples of water collected at every 50 fathoms, from 400 fathoms to the bottom at 862 fathoms, the percentage results being as follows:—

	750 fath.	800 fath.	Bottom, 862 fath.
Oxygen	18·8	17·8	17·2
Nitrogen........	49·3	48·5	34·5
Carbonic Acid....	31·9	33·7	48·3

The extraordinarily augmented percentage of Carbonic Acid in the stratum of water here immediately overlying the Sea-bed was accompanied by a great abundance of Animal life. On the other hand, the lowest percentage of Carbonic Acid found in bottom-water (viz. 7·9) was accompanied by a "very bad haul." In several cases in which the depths were nearly the same, the analyst ventured a prediction as to the abundance, or otherwise, of Animal life, from the proportion of Carbonic Acid in the bottom-water; and his prediction proved in every instance correct.

131. It would appear probable, therefore, that the increase in the proportion of Carbonic Acid, and the diminution in that of the Oxygen, in the abyssal waters of the Ocean, is due to the Respiratory process; which is no less a necessary condition of the existence of Animal life on the sea-bed than is the presence of food-material for its sustenance. And it is further obvious that the continued consumption of Oxygen and liberation of Carbonic Acid would soon render the stratum of water immediately above the bottom completely irrespirable (in the absence of any antagonistic process of Vegetation) were it not for the upward diffusion of the Carbonic Acid through the intermediate waters to the surface, and the *downward* diffusion of Oxygen *from* the surface to the depths below. A continual interchange will take place *at* the surface between the gases of the Sea-water and those of the Atmosphere; and thus the Respiration of the Abyssal Fauna is provided for by a process of diffusion, which may have to operate through *three miles* or more of intervening water.

132. The varying proportions of Carbonic Acid and Oxygen in the *surface*-waters are doubtless to be accounted for in part by the differences in the amount and character of the Animal life existing beneath; but a comparison of the results of the analyses made during the agitation of the surface by wind, with those made in calm weather, showed so decided a reduction in the proportion of Carbonic Acid, with an increase in that of Oxygen, under the former condition, as almost unequivocally to indicate that superficial disturbance of the sea by Atmospheric movement is absolutely necessary for its purification from the noxious effects of Animal decomposition. Of this view a most unexpected and remarkable confirmation has been afforded by the following circumstance:—In one of the analyses of Surface-water made during the Second cruise, the percentage of Carbonic Acid fell as low as 3·3, while that of Oxygen rose as high as 37·1; and in a like analysis made during the Third cruise, the percentage of Carbonic Acid was 5·6, while that of Oxygen was 45·3. As the results of every other analysis of Surface-water were in marked contrast to these, it became a question whether they should not be thrown out as erroneous; until it was recollected that whilst the samples of surface-water had been generally taken up from the *bow* of the vessel, they had been drawn, in these two instances, from *abaft the paddles*, and had thus been subjected to such a violent agitation in contact with the Atmosphere as would preeminently favour their thorough aëration.—Hence, then, it may be affirmed that every disturbance of the Ocean-surface by Atmospheric movement, from the gentlest ripple to the most tremendous storm-wave, contributes, in proportion to its amount, to the maintenance of Animal life in its Abyssal depths; doing, in fact, for the aëration of the fluids of their inhabitants just what is done by the heaving and falling of the walls of our own chest for the aëration of the blood which courses through our lungs. A perpetual calm would be as fatal to their continued existence as the forcible stoppage of all Respiratory movement would be to our own; and thus universal stagnation would become universal death.

APPENDIX.

I.—*Summary of the Results of the Examination of Samples of Sea-water taken at the Surface and at Various Depths.* By Wm. Lant Carpenter, B.A., B.Sc.

Surface-waters.—Care was taken to obtain these samples as pure as possible, and free from any contamination caused by matters derived from the vessel, by dipping them up in clean vessels at a few inches below the surface at or near the bow of the ship. In two instances, however, the samples were taken from abaft the paddles.

Waters taken at depths below the surface.—It was found desirable to coat the brass Water-Bottles (§ 19) internally with sealing-wax varnish, owing to the corrosive action of the sea-water. The apparatus was then found to work perfectly satisfactorily in all cases in which there was sufficient weight on the Sounding-line to which they were attached to keep the bottles perpendicular, or nearly so. When, from the smallness of the attached weight, or the roughness of the sea, the sounding-line was at an acute angle with the general level of the sea-surface while it was being drawn up, the results of the examination of water thus obtained rendered it highly probable that some water at or near the surface had found its way into the bottle, and that its contents were not to be relied on as coming from the lowest depths.

When Bottom-water was obtained from depths beyond 500 fathoms, it was almost invariably charged with a quantity of very fine mud in suspension, rendering it quite turbid. Many hours' standing was necessary for the deposit of this; but it was readily removed by filtration. In no instance was there any evidence of water from great depths being much more highly charged with dissolved gases than Surface-waters; a considerable elevation of temperature being in *all* cases necessary for the evolution of any dissolved gas.

Mode of Examining Samples.—The samples of water thus taken were examined with as little delay as possible, with a view to determine:—

(1) The Specific Gravity of the water.

(2) The total quantity of dissolved Gases contained in them, and the relative proportions of Oxygen, Nitrogen, and Carbonic Acid.

(3) The quantity of Oxygen necessary to oxidize the Organic matter contained in the water; distinguishing between

a, the decomposed organic matter, and

b, the easily decomposable organic matter.

(1) The Specific-Gravity determinations were made at a temperature as near 60° Fahr. as possible, with delicate glass Hydrometers, so graduated that the Specific gravity could be read off directly to the fourth decimal place with ease.

(2) The apparatus for the analysis of the Gases dissolved in the sea-water was essentially that described by Prof. Miller in the second volume

of his 'Elements of Chemistry.' It was found necessary to make several modifications in it, to adapt it to the motion of the vessel. These consisted chiefly in suspending much of it from the cabin-ceiling, instead of supporting it from beneath, and in rendering all the parts less rigid by a free use of caoutchouc tubing, &c., the utmost care being taken to keep all joints tight.

It was found possible to make correct analyses, even when the vessel was rolling sufficiently to upset chairs and cabin-furniture.

The method of Analysis may be thus summarized:—From 700 to 800 cubic centimetres of the sample to be examined were boiled for about 30 minutes, in such a way that the steam and mixed gases evolved were collected over mercury in a small graduated Bunsen's Gas-holder, all access of air being carefully guarded against. The mixed gases were then transferred to two graduated tubes in a mercurial trough, where the Carbonic Acid was first absorbed by a strong solution of caustic potash; and subsequently the Oxygen was absorbed by the addition of pyrogallic acid, the remaining gas being assumed to be Nitrogen.

The results of the analyses were always corrected to the standard Temperature of 0° Cent., and to 760 millimetres Barometric pressure, for comparison among themselves and with others. In nearly every case the duplicate analyses from the same gaseous mixture agreed closely, if they were not identical.

(3) The examination of the Sea-water for Organic matter was made according to the method detailed by Prof. Miller in the Journal of the Chemical Society for May 1865, with an addition suggested by Dr. Angus Smith. Each sample of water was divided into two; to one of these a little free acid was added, and to both an excess of a standard solution of Permanganate of potash. At the end of three hours the reaction was stopped by the addition of Iodide of potassium and Starch, and the excess of Permanganate estimated by a standard solution of Hyposulphite of soda. The portion to which free acid was added gave the Oxygen required to oxidize the decomposed and easily decomposable organic matter; the second portion gave the oxygen required by the decomposed organic matter alone, which was usually from about one-half to one-third of the whole.

The following is a Summary of the total number of observations, analyses, &c. made during the Three Cruises respectively:—

	First Cruise.	Second Cruise.	Third Cruise.	Total.
Specific-Gravity determinations .	72	27	26	125
Duplicate Gas-analyses	45	23	21	89
Organic-matter tests	137	26	32	195

Specific Gravity.—The Specific Gravity of Surface-water was found to diminish slightly as land was approached; but the average of 32 observations upon water at a sufficient distance from land to be unaffected by local disturbances was 1·02779, the maximum being 1·0284
and the minimum.... 1·0270.

It was almost always noticed that, during a high wind, the specific gravity of surface-water was *above* the average.

The average of 30 observations upon the Specific Gravity of Intermediate water was 1·0275,
the maximum being.......... 1·0281,
and the minimum .... 1·0272.

The Specific Gravity of Bottom-waters at depths varying from 77 to 2090 fathoms, deduced from an average of 43 observations, was
1·0277,
the maximum being.......... 1·0283,
and the minimum............ 1·0267.

It will be noticed that the average Specific Gravity of Bottom-water is slightly less than that of Surface-water. In several instances the Specific Gravities of Surface- and of Bottom-waters taken at the same place having been compared, that of the Bottom-water was found to be appreciably less than that of the Surface-water. Thus

At 1425 fathoms depth (Station 17) it was .. 1·0269
Surface at the same .... 1·0280

And

At 664 fathoms depth (Station 26 *b*) it was .. 1·0272
Surface at the same...................... 1·0280

According, however, to a Series of observations made at the same spot (Station 42) at intervals of 50 fathoms, from 50 to 800, the Specific Gravity increased with the depth from 1·0272 at 50 fathoms to 1·0277 at 800 fathoms*.

Several series of Sp.-Gr. observations were made near the mouths of rivers and streams; showing the gradual mixture of fresh and salt water, and the floating of lighter portions above the denser sea-water, as well as the reverse effect produced by the influence of tidal currents. Thus outside Belfast Lough a rapid stream of water of Sp. Gr. 1·0270 was found above water which at a depth of 73 fathoms had a Sp. Gr. of 1·0265.

Gases of Sea-water.—The analyses of the Gaseous constituents of sea-water may be divided into two groups: (1) Analyses of Surface-waters. (2) Analyses of waters below the surface; and these last may be again subdivided into (*a*) Intermediate, and (*b*) Bottom-waters.

The total quantity of dissolved gases in sea-water, whether at the surface or below it, was found to average about 2·8 volumes in 100 volumes of water.

* My own experience of the difficulty of making accurate Hydrometric determinations when the ship was rolling prevents me from attaching much value to the above results.—W. B. C.

The average of 30 analyses of Surface-waters made during the Expedition gave the following proportions :—

	Percentage.	Proportion.
Oxygen	25·046	100
Nitrogen	54·211	216
Carbonic acid	20·743	80
	100·000	

These were thus distributed over the three Cruises, and the maxima and minima of each constituent are thus shown.

	Number of analyses	Average percentage.			Average proportion.			Oxygen.		Nitrogen.		Carbonic acid	
		Oxygen.	Nitrogen.	Carbonic acid.	O.	N.	CO_2	Max. per cent.	Min. per cent.	Max. per cent.	Min. per cent.	Max. per cent.	Min. per cent.
First Cruise	19	24·47	52·95	22·58	100	216	92	28·78	19·60	62·95	46·35	32·0	12·72
Second Cruise	2	31·33	54·85	13·82	100	175	44	37·10	25·56	59·63	50·07	24·37	3·27
Third Cruise	9	24·86	56·73	18·41	100	228	74	45·28	13·98	68·67	41·42	27·14	5·64

It is interesting to remark that Surface-water contains a greater quantity of Oxygen and a less quantity of Carbonic acid during the prevalence of strong wind. The following is an average of 5 analyses made under such conditions :—

		Per cent.	Proportion.	General average.	
5	Oxygen........	29·10	100	25·046	100
	Nitrogen	52·87	182	54·211	216
	Carbonic acid ..	18·03	62	20·743	83

In the two cases which presented the remarkable small *minima* of Carbonic acid with a great excess of Oxygen, the water had been accidentally taken from immediately abaft the paddles, where it had been subject to violent agitation in contact with air.

Of water at various depths beneath the surface, 59 analyses were made. Those in the First cruise, 26 in nnmber, were chiefly from Bottom-water at depths from 25 to 1476 fathoms. In the Second cruise the 21 analyses chiefly belonged to two Series,—the first of samples taken at intervals of 250 fathoms, from 2090 to 250 fathoms, inclusive ; and the second of samples taken at intervals of 50 fathoms from 862 to 400 fathoms inclusive. In the Third cruise 12 analyses were made,—8 of Bottom-water, of which one-half were in the "cold area," and 4 at Intermediate depths.

The general average of the 59 analyses of water taken below the surface gives :—

Oxygen	20·568	100
Nitrogen	52·240	254
Carbonic acid	27·192	132
	100·000	

It will be seen from this that while the quantity of Nitrogen is only 1·97 per cent. less than in surface-water, the quantity of Oxygen is diminished by 4·48 per cent., and the quantity of Carbonic acid increased by 6·45 per cent. This difference is greater if Bottom-waters only are compared with Surface-waters.

	30 Surface.		24 Intermediate.		35 Bottom.	
	Per cent.	Proportion.	Per cent.	Proportion.	Per cent.	Proportion.
Oxygen	25·05	100	22·03	100	19·53	100
Nitrogen	54·21	216	51·82	235	52·60	261
Carbonic acid	20·74	83	26·15	119	27·87	143
	100·00		100·00		100·00	

The two Series of analyses, before referred to, performed during the Second cruise upon Intermediate waters at successive depths over the same spot both show a regular increase of the Carbonic acid, and diminution of the Oxygen, as the depth increases, the percentage of Nitrogen varying but slightly.

These general results appear to show that the Oxygen diminishes and the Carbonic acid increases with the depth until the bottom is reached; but that *at* the bottom, whatever the depth from the surface, the proportions of Carbonic acid and of Oxygen do not conform to this law, Bottom-water at a comparatively small depth often containing as much carbonic acid and as little oxygen as Intermediate water at a greater depth. No instance occurred during the first two Cruises in which (where samples of surface and intermediate or bottom-waters were taken at the same place) the quantity of Carbonic acid was less and of Oxygen greater than at the surface; the only exception occurred in the Third cruise, at a place where, it is believed, currents of water were meeting.

It was frequently noticed that a large percentage of Carbonic acid in Bottom-water was accompanied by an abundance of Animal life, as shown by the dredge; and that where the dredge-results were barren, the quantity of Carbonic acid was much smaller. The greatest percentage of Carbonic acid ever found was accompanied by an abundance of life; while at a short distance (62 fathoms) above the bottom, the proportion of Carbonic acid was conformable to the law of variation with depth before referred to:

	Bottom, 862 fms.	800 fms.	750 fms.
Oxygen..........	17·22	17·79	18·76
Nitrogen	34·50	48·46	49·32
Carbonic acid	48·28	33·75	31·92
	100·00	100·00	100·00

The lowest percentage of Carbonic acid (7·93) ever found in Bottom-water, occurring at a depth of 362 fathoms, was accompanied by a "very bad haul."

In crossing the wide channel from the N.W. of Ireland towards Rockall, where the water for some distance is over 1000 fathoms depth, so that the other circumstances varied very little, if at all, the proportion of Carbonic acid appeared to vary with the dredge-results; so that the analyst ventured to predict whether the collection would be good or not before the dredge came to the surface—drawing his inference from the results of his analyses of the gases of the Bottom-water. In each case his prediction was justified by the result.

	Station 17. 1425 fms.	Station 19. 1360 fms.	Station 20. 1443 fms.	Station 21. 1476 fms.
Oxygen	16·14	17·92	21·34	16·68
Nitrogen	48·78	45·88	47·51	43·46
Carbonic acid ..	35·07	36·20	31·15	39·86
	100·00	100·00	100·00	100·00
	Good haul.	Good haul.	Bad haul.	Good haul.

In the analyses made of the water in the Cold Area, and generally in the Third cruise, there appears, as might be expected from the various currents &c., a greater variation in the results than in the other series. In the Bottom and Intermediate waters the Nitrogen appears to be rather in excess of the average, and the Carbonic acid has a large range of variation—from 7·58 per cent. at Station 47 (540 fathoms, Temp. 43°·8) to 45·79 per cent. at Station 52 (384 fathoms, 30°·6 Fahr.). The average of the Surface-waters is much the same as in the other parts of the cruise.

It may be worth notice that in localities where the greatest depth did not exceed 150 fathoms, the results of the gas-analysis of Bottom and Surface-water were frequently so nearly the same, whatever the amount of Animal life on the bottom, as to lead to the supposition that there might be at that limit a sufficient circulation, either of the particles of the water itself or of the gases dissolved in it, to keep the gaseous constitution alike throughout. The coincidence of this depth with the extreme depth at which Fish are usually found to exist in these seas is suggestive.

Organic matter.—With a view to test the method of analysis by Permanganate of potash, two or three series of analyses were made where fresh and salt water mixed together, as in Killibegs Harbour, Donegal Bay, &c.; and the results in all cases justified the expectation formed, that the amount of permanganate was an index of the comparative purity of the water, both as regards the "decomposed" and the "decomposable" organic matter.

Disregarding the above series, a total of 134 experiments were made upon Sea-water, which may be thus divided:—

56	upon	Surface-water,
18	,,	Intermediate water,
60	,,	Bottom-water,
134		

during the First and Third cruises.

The results are given in the quantity of Oxygen in fractions of a gramme required to oxidize the Organic matter in a litre of water.

Average of 56 analyses of Surface-water :—

No.			
28.	Decomposed......	0·00025	Total 0·00095.
28.	Decomposable....	0·00070	

	Maximum.	Minimum.	
Decomposed......	0·00094	0·00000	4 cases.
Decomposable	0·00100	0·00000	1 case.
Total	0·00194	0·00000	1 case.

Average of 18 analyses of Intermediate water :—

No.			
9.	Decomposed	0·00005	Total 0·00039.
9.	Decomposable	0·00034	

In 7 out of 9 there was no "decomposed" Organic matter; and in 3 out of 9 there was no Organic matter at all, as indicated by this test.

In this series the analyses of the observations made during the Second cruise are not included, as the calculations have been differently made.

Average of 60 analyses of Bottom-water :—

No.			
26.	Decomposed......	0·00047	Total 0·00088.
34.	Decomposable	0·00041	

	Maximum.	Minimum,	
Decomposed......	0·00105	0·00000	2 cases.
Decomposable	0·00148	0·00000	1 case.
Total	0·00253	0·00000	1 case.

These figures appear to show (1) that Intermediate waters are more free from Organic contamination than either Surface- or Bottom-waters, as might be expected from the comparative absence of animal life in these waters; (2) that the total absence of Organic matter is least frequent in Bottom-waters, and most frequent in Intermediate waters, Surface-waters occupying a middle place in this respect; and (3) that there is not much difference between Bottom- and Surface-waters, either in the total quantity of Organic contamination or in the relative proportions of the "decomposed" and "easily decomposable" organic matter.

It may be worth notice that when the Bottom-water from great depths was muddy, tests made before and after filtration showed that some of the Organic matter was removed by this operation.

II.—*Results of the Analysis of Eight Samples of Sea-Water collected during the Third Cruise of the 'Porcupine.'* By Dr. Frankland, F.R.S.

Royal College of Chemistry.
November 15th, 1869.

Dear Dr. Carpenter,—Herewith I enclose results of analyses of the samples of sea-water collected during your recent cruise in the 'Porcupine.'

I shall not attempt to draw any general conclusions from these results; your own intimate knowledge of the circumstances under which the different samples were collected will enable you to do this much better than I.

There is, however, one point which is highly remarkable and to which I would draw your attention; it is the large amount of very highly nitrogenized Organic matter contained in most of the samples, as shown by the determinations of organic Carbon and organic Nitrogen, and the proportion of organic Carbon to organic Nitrogen. For the purposes of comparison, I have appended the results of analyses of Thames-water and of the water of Loch Katrine, the former representing probably about a fair average of the proportion of organic nitrogen reaching the sea in the rivers of this country, but being presumably considerably greater than that contributed by rivers in other parts of the world. If this be so, it follows either that soluble nitrogenous organic matter is being generated from inorganic materials in the sea, or that this matter is undergoing concentration by the evaporation of the ocean,—the rivers and streams continually furnishing additional quantities whilst the water evaporated takes none away.

The amounts of Carbonate of Lime given in the Table are obtained by adding the number 3 (representing the solubility of carbonate of lime in pure water) to the temporary hardness which denotes the carbonate of lime thrown down on boiling. As the determination of temporary hardness in water containing so much saline matter is not very accurate, the numbers in the columns headed "temporary hardness" and "carbonate of lime" must only be regarded as rough approximations to the truth; moreover, a small proportion of carbonate of magnesia is mixed with the carbonate of lime and estimated with it.

In all their peculiar features these analytical results agree with those which I have previously obtained from numerous samples of sea-water collected by myself off Worthing and Hastings.

Yours very truly,
E. Frankland.

Results of Analysis expressed in Grammes per 100,000 Cubic Centimetres of Water.

Number of Sample.	Description.	Sp. Gravity at 15°·5 C.	Total Solid matter in solution.	Organic Carbon.	Organic Nitrogen.	Proportion of org nic N. to organic C.	Ammonia.	Nitrogen as Nitrates and Nitrites.	Total combined Nitrogen.	Silica.	Chlorine.	Hardness. Temporary.	Hardness. Permanent.	Hardness. Total.	Carbonate of Lime, Approximate.
No. 47	Surface, Temp. 54°	1·0268	4074	·647	·134	1 : 4·83	·022	·030	·182	·90	2028·1	70·7	818·3	889·0	73·7
47	Bottom, 542 fathoms, Temp. 43°·8	1·0268	4070	·331	·163	1 : 2·03	·022	·032	·213	—	2034·4	42·4	832·4	874·8	45·4
87	Surface, Temp. 52°·6	1·0269	4036	·321	·098	1 : 3·38	·017	·056	·168	2·10	1987·5	98·9	804·2	903·1	101·9
87	Bottom, 767 fathoms, Temp. 41°·4	1·0268	4132	·313	·096	1 : 3·26	·020	·061	·173	1·10	2026·9	84·8	818·3	903·1	87·8
54	Surface, Temp. 52°·5	1·0266	4110	·281	·169	1 : 1·61	·007	·025	·200	·75	2017·5	42·4	818·3	860·7	45·4
54	Bottom, 363 fathoms, Temp. 31°·4	1·0258	4030	·136	·161	1 : ·84	·004	·041	·205	·10	2014·4	56·5	860·7	917·2	59·5
64	Surface, Temp. 49°·7	1·0265	4116	·170	·217	1 : ·78	·005	·043	·264	·30	1996·2	56·5	860·7	917·2	59·5
64	Bottom, 640 fathoms, Temp. 29°·6	1·0262	3920	·217	·252	1 : ·86	·008	·039	·298	·10	1988·1	56·5	846·6	903·1	59·5
	Thames, mid-stream at low water, London Bridge, April 27th, 1869.	...	30·35	·455	·075	1 : 6·07	·032	·181	·282	...	1·95	...	...	22·7	
	Water of Loch Katrine	...	3·00	·161	·011	1 : 14·64	·001	·000	·012	...	·905	...	...	·3	

III.—*Notes on Specimens of the Bottom collected during the First Cruise of the 'Porcupine' in* 1869. By David Forbes, F.R.S.

Atlantic Mud contained in a small bottle marked "Soundings No. 20, 1443 fathoms."

A complete analysis of this sample shows its Chemical Composition to be as follows:—

Carbonate of lime	50·12
Alumina * ("soluble in acids")	1·33
Sesquioxide of iron ("soluble in acids")	2·17
Silica (in a soluble condition)	5·04
Fine insoluble gritty sand (rock débris)	26·77
Water	2·90
Organic matter	4·19
Chloride of sodium and other soluble salts	7·48
	100·00

If we compare the chemical composition as above with that of ordinary Chalk, which consists all but entirely of carbonate of lime, and seldom contains more than from 2 to 4 per cent. of foreign matter (clay, silica, &c.), it will be seen that it differs chiefly in containing so very large an amount of rock-matter in a fine state of division. If we subtract the water, organic matter, and marine salts, which would probably in greatest part be removed before such mud could in process of ages be converted into solid rock, even then the amount of carbonate of lime or pure chalk would not be more than at highest some 60 per cent. of the mass.

As such deposits must naturally be expected to vary greatly in mechanical character and chemical composition, it would be premature to generalize as to the actual nature of the deposits now in course of formation in the depths of the Atlantic, before a careful examination had been made of a series of such specimens from different localities. The soluble silica is principally from siliceous organisms.

[Mr. Hunter's analysis of the Atlantic Mud brought up from the 2435 fathoms' dredging, will be found in p. 428].

As regards the probable origin of the pebbles and gravel found in the various dredgings, it will be at once seen, from the description, that they consist principally of fragments of volcanic rocks and crystalline schists. The former of these have in all probability come from Iceland or Jan Mayen; whilst the latter, associated as they are with small fragments of grey and somewhat altered calcareous rock, would appear to have proceeded from the north-west coast of Ireland, where the rocks are quite identical in mineral character. The north of Scotland and its islands also contain similar rocks; but without being at all positive on this head, I am

* With phosphoric acid.

rather inclined to the opinion that they have been derived from Ireland, and not necessarily connected with any glacial phenomena, believing that their presence may be accounted for by the ordinary action of marine currents.

"Pebbles from 1215 fathoms (Station 28)."

The stones were all subangular, the edges being all more or less worn or altogether rounded off. The specimens were 38 in number, and upon examination were found to consist of:—

5 Hornblende schist; the largest of these (which also was the largest in size of the entire series) weighed 421 gr. ($\frac{7}{8}$ of an ounce), was extremely compact, and was composed of black hornblende, dirty-coloured quartz, and some garnet.
2 Mica schist; quartz with mica, the largest weighing 20 grains.
5 Grey pretty compact limestone, the largest being 7 grains in weight.
2 Fragments (showing the cleavage faces rounded off on edges) of orthoclase (potash felspar), evidently derived from granite; the largest of the two fragments weighed 15 grains.
5 Quartz, milky in colour or colourless; the largest of these weighed $90\frac{3}{4}$ grains, and showed evidence of having been derived from the quartz-veins so common in clay-slate.
19 Fragments of true volcanic lava, most of which were very light and
— scoriaceous (vesicular), although some small ones were compact and
38 crystalline; and in these the minerals augite, olivine, and glassy felspar (Sanadine) could be distinctly recognized. Amongst these were fragments of trachytic trachydoleritic, and pyroxenic (basaltic) lavas, quite similar to those of Iceland or Jan Mayen of the present period, from which they had probably been derived.

"Gravel from 1443 fathoms (Station 20)."

This sample of gravel consisted of 718 subangular fragments, in general not above from $\frac{1}{4}$ to $\frac{1}{2}$ grain in weight, with occasionally some of a little greater size; but the most considerable of all (a fragment of mica schist) only weighed 3 grains. They consisted of:—

3 Fragments of orthoclase felspar.
4 Bituminous or carbonaceous shale (? if not accidental).
5 Fragments of shell (undistinguishable species).
4 Granite, containing quartz, orthoclase, and muscovite.
15 Grey compact limestone.
62 Quartzose mica schist.
317 Hornblende schist; sometimes containing garnets.
273 Quartzite fragments, with a very few fragments of clear quartz; the majority of the pieces being of a dirty colour, often cemented together, were evidently the débris of quartzite rocks or beds of indurated sandstone, and not from granite.
28 Black compact rock containing augite, most probably a volcanic
—— basalt.
718

"From 1263 fathoms (Station 22)."

A single rounded pebble, weighing 18 grains, chiefly quartz, with a little of a black mineral hornblende or tourmaline, probably from a metamorphic schist.

"Gravel from 1366 fathoms (Station 19*a*)."

Consisted of 51 small subangular pieces of rock, all less than ½ grain in weight, excepting only one fragment (angular) of quartz, which weighed 2 grains; they consisted of:—

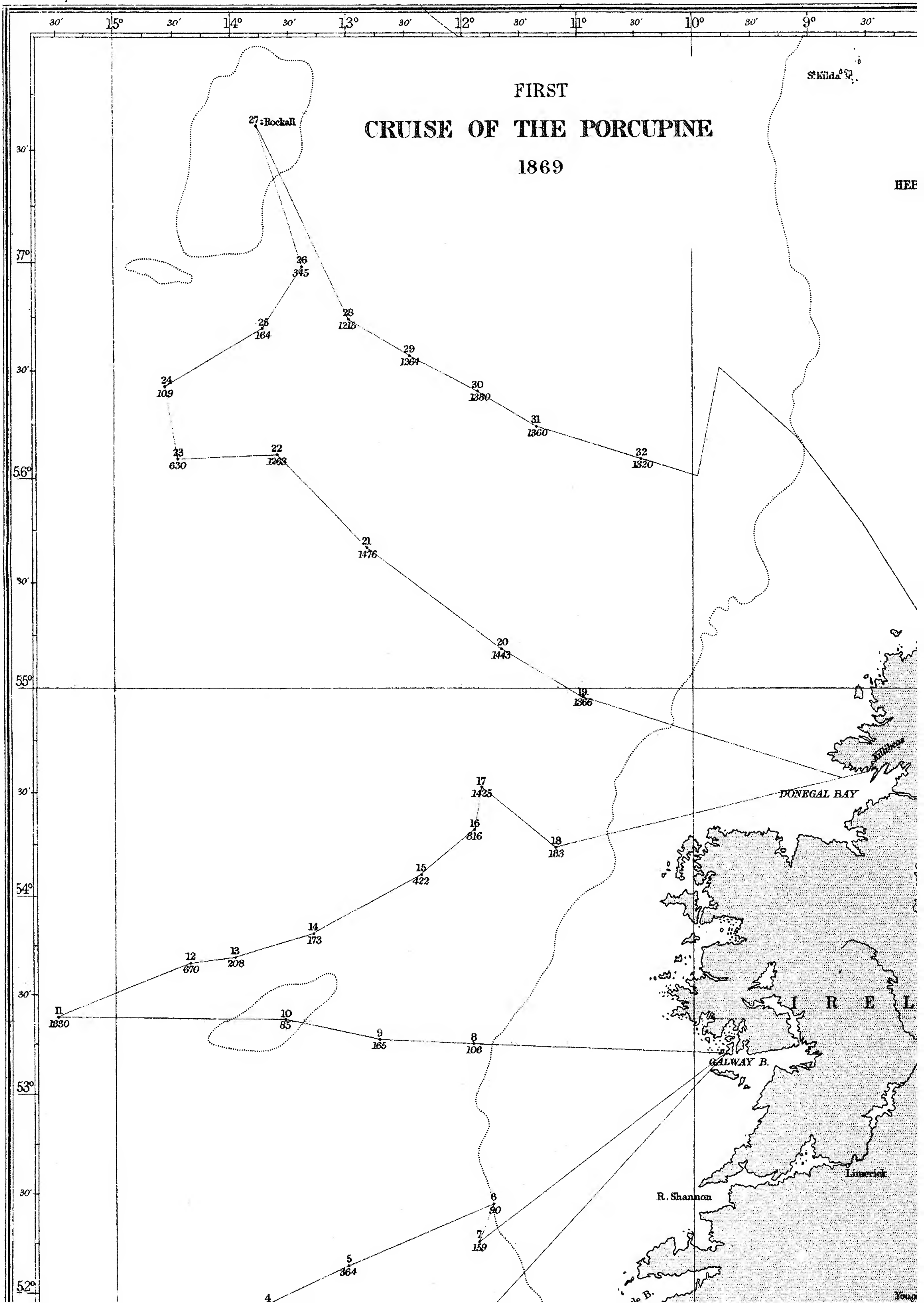
19 Fragments of quartz, all of which appeared to have proceeded from the disintegration of crystalline schists, and not from granite.
9 Hornblende schist.
8 Mica schist.
7 Loose, dirty-white tufaceous limestone.
3 Small fragments of augite or tourmaline (? which).
1 Fragment of quartz, with tourmaline.
4 Fragments of indistinct and uncertain character.
51

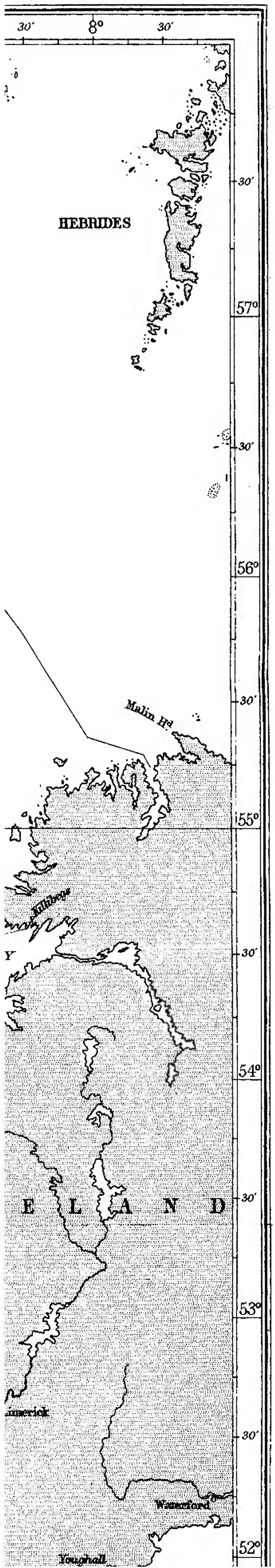
"Gravel from 1476 fathoms (Station 21)."

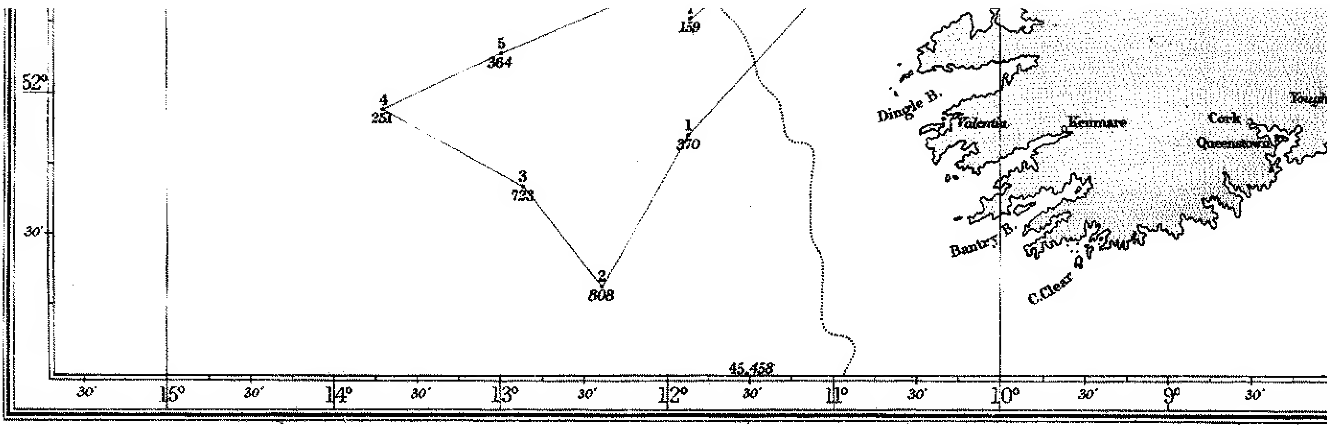
Six small subangular fragments, the largest of which did not exceed two grains in weight; they were respectively:—

1 Yellow quartz.
1 Quartzose chlorite schist.
3 Mica schist.
1 Small fragment, apparently of volcanic lava.
6

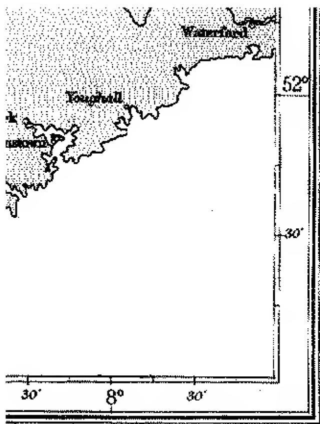
The specimen from Rockall is not a fragment of any normal rock, but is only a brecciaform aggregate, principally consisting of quartz, felspar, and crystals of green hornblende, held together by a siliceous cement. It has evidently been broken from the projecting edge of a fault or vein fissure; and although it cannot settle the matter definitely as to what rocks this islet may really be composed of, it would indicate that it most probably is a mass of hornblendic gneiss or schist, and certainly not of true volcanic origin. I may mention that it does not at all resemble any of the fragments found in the deep-sea dredgings which I have as yet examined.


FIRST
CRUISE OF THE PORCUPINE
1869
27 Rockall
26 345
25 164
24 109
23 630
22 1263
21 1476
20 1443
19 1366
28 1215
29 1264
30 1380
31 1360
32 1320
17 1425
16 816
18 183
15 422
14 173
13 208
12 670
11 1830
10 85
9 165
8 106
6 90
7 159
5 364
4
St Kilda
HEB
DONEGAL BAY
Killibegs
I R E L
GALWAY B.
R. Shannon
Limerick
57°
56°
55°
54°
53°
52°
15°
14°
13°
12°
11°
10°
9°
30′


30'
8°
30'
30'
HEBRIDES
57°
30'
56°
30'
Malin Hd
55°
Killibegs
30'
54°
30'
E L A N D
53°
Limerick
30'
Waterford
Youghall
52°



52°
30'
5
364
4
251
1
370
3
723
2
808
159
45,458
Dingle B.
Valentia
Kenmare
Cork
Queenstown
Bantry B.
C.Clear
30'
15°
30'
14°
30'
13°
30'
12°
30'
11°
30'
10°
30'
9°
30'



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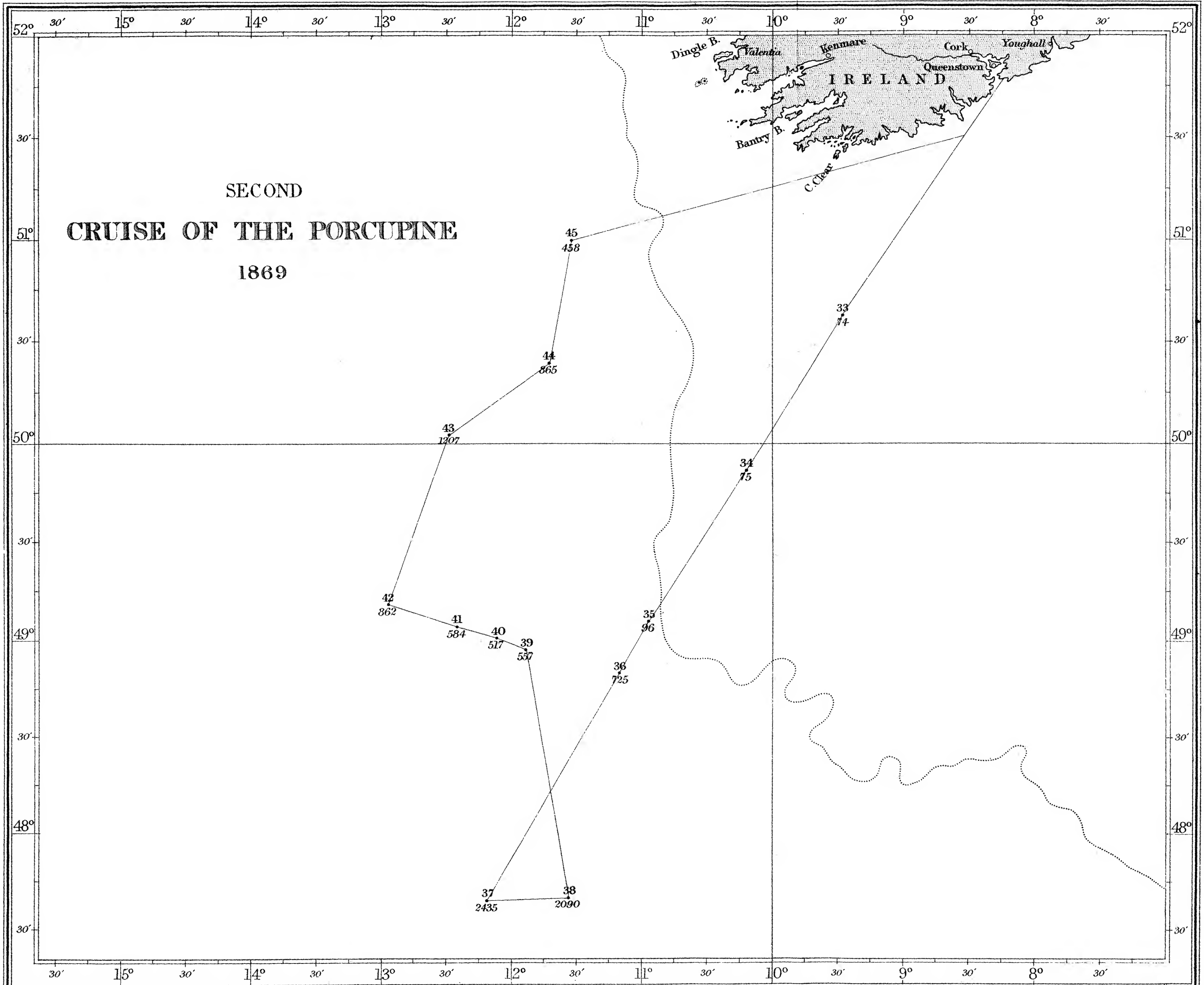
FIRST CRUISE OF THE 'PORCUPINE' (Plate 4).

Station No.	North Latitude.		West Longitude.		Depth in Fathoms.	Surface Temperature, Fahrenheit.	Bottom Temperature, Fahrenheit.
1.	51°	51′	11°	50′	370	54°·2	49°·0
2.	51	22	12	25	808	54·2	41·4
3.	51	38	12	50	722	54·5	43·0
4.	51	56	13	39	251	53·5	49·5
5.	52	7	12	52	364	54·0	48·8
6.	52	25	11	40	90	54·0	50·0
7.	52	14	11	48	159	53·2	50·4
8.	53	15	11	51	106	54·2	51·2
9.	53	16	12	42	165	53·5	49·7
10.	53	23	13	29	85	54·6	49·5
11.	53	24	15	24	1630	......	......
12.	53	41	14	17	670	52·2	42·6
13.	53	42	13	55	208	53·6	49·6
14.	53	49	13	15	173	53·2	49·6
15.	54	5	12	17	422	52·2	47·0
16.	54	19	11	50	816	53·0	39·5
17.	54	28	11	44	1230	53·2	37·8
18.	54	15	11	9	183	53·2	49·4
19.	54	53	10	56	1360	54·8	37·4
20.	55	11	11	31	1443	55·5	37·0
21.	55	40	12	46	1476	56·2	36·9
22.	56	8	13	34	1263	56·9	37·3
23.	56	7	14	19	630	57·3	43·5
23*a*.	56	13	14	18	420	56·8	46·4
24.	56	26	14	28	109	57·7	46·4
25.	56	41	13	39	164	56·8	46·5
26.	56	58	13	17	345	57·4	46·7
27.	Rockall Bank.		Rockall Bank.		54	55·6	48·3
28.	56	44	12	52	1215	57·6	37·1
29.	56	34	12	22	1264	56·9	36·9
30.	56	24	11	49	1380	56·0	37·1
31.	56	15	11	25	1360	56·9	37·2
32.	56	5	10	23	1320	55·9	37·4



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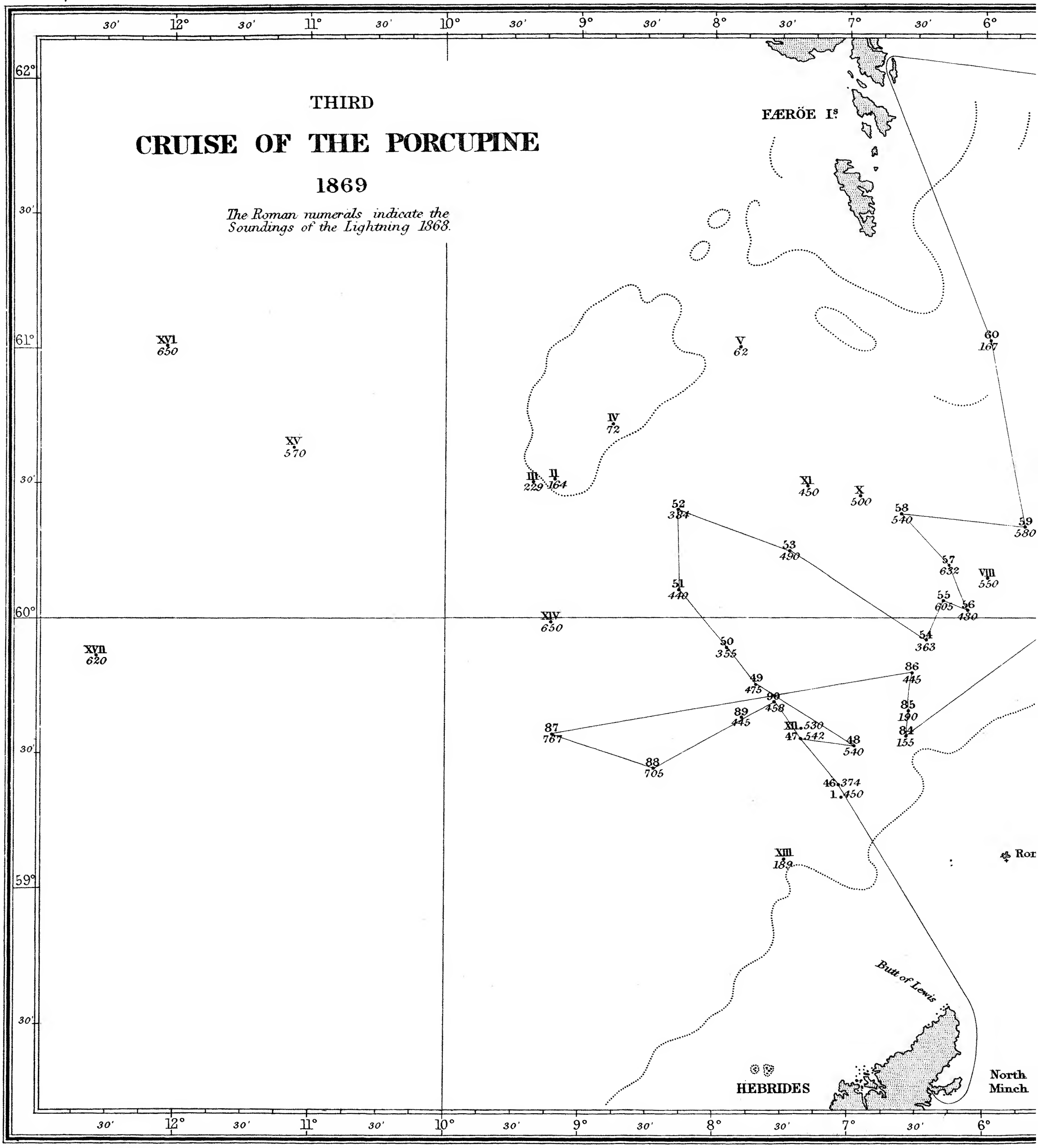
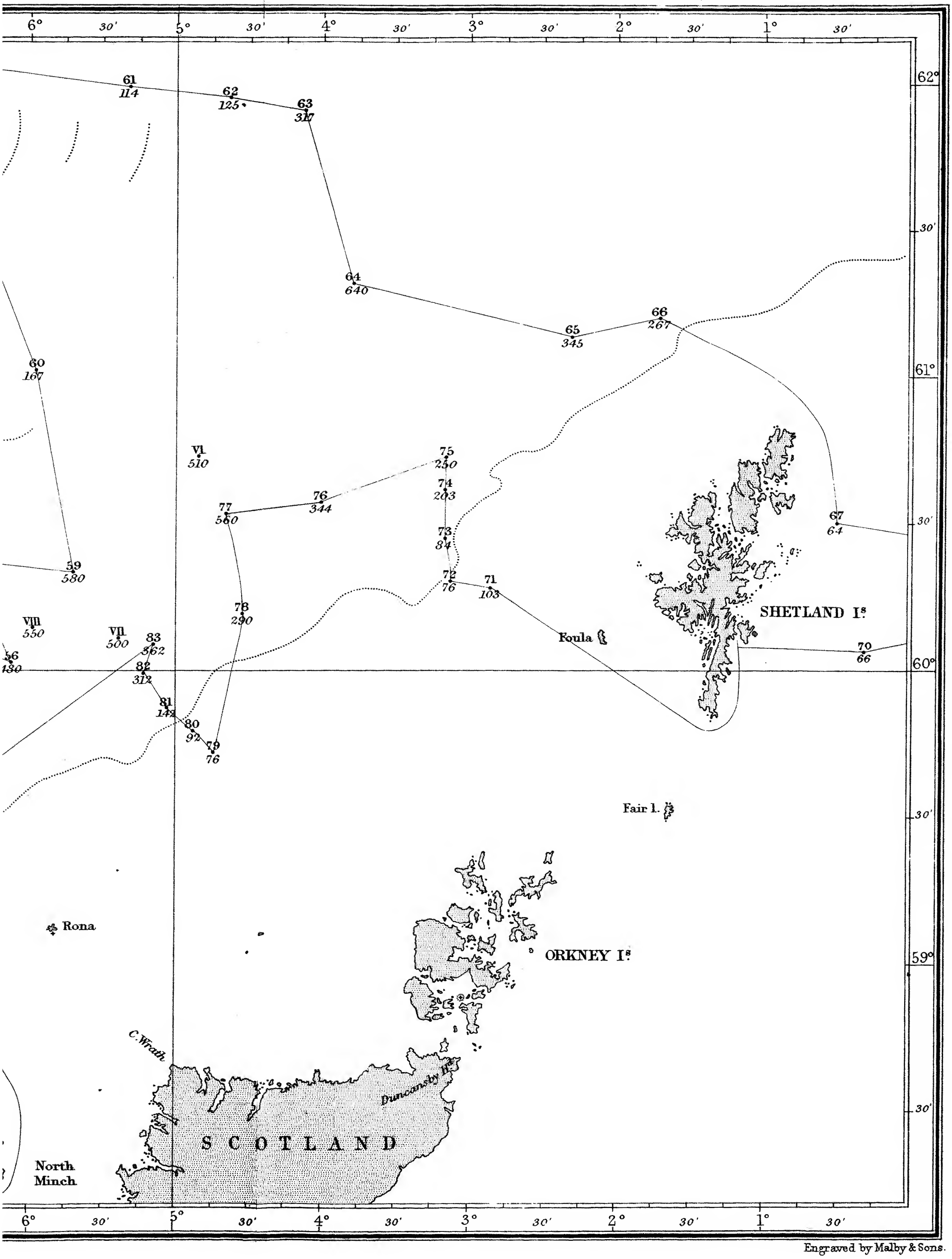
Second Cruise of the 'Porcupine' (Plate 5).

Station No.	North Latitude.		West Longitude.		Depth in Fathoms.	Surface Temperature, Fahrenheit.	Bottom Temperature, Fahrenheit.
33.	50°	38′	9°	27′	74	65°·2	49°·6
34.	49	51	10	12	75	66·0	49·6
35.	49	7	10	57	96	63·4	51·3
36.	48	50	11	9	725	64·0	43·9
37.	47	38	12	8	2435	65·6	36·5
38.	47	39	11	33	2090	64·2	36·3
39.	49	1	11	56	557	63·0	47·0
40.	49	1	12	5	517	63·4	47·7
41.	49	4	12	22	584	63·4	46·5
42.	49	12	12	52	862	62·6	39·7
43.	50	1	12	26	1207	61·7	37·7
44.	50	20	11	34	865	61·2	39·4
45.	51	1	11	21	458	60·6	48·1

Dr. Carpenter





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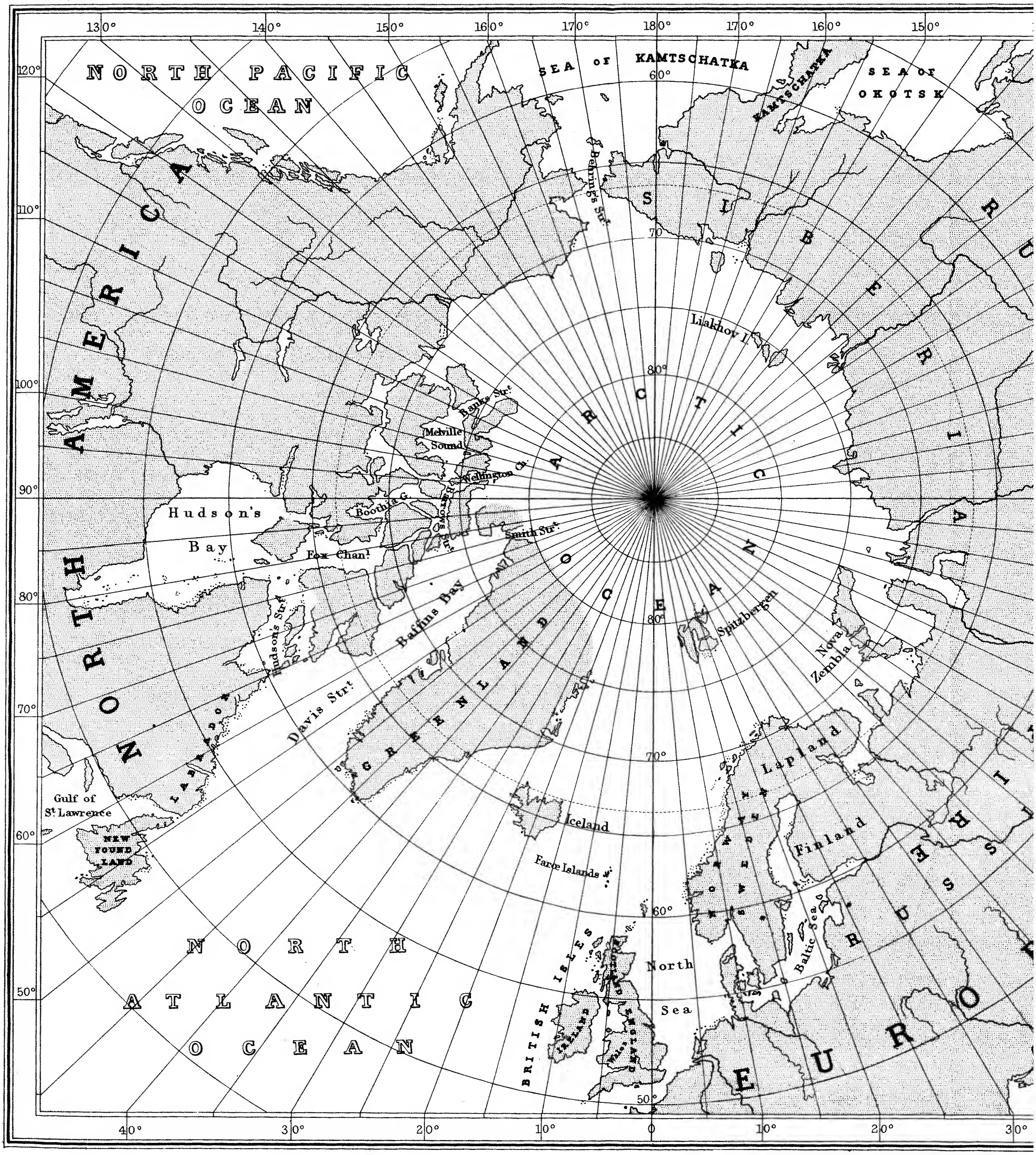
THIRD CRUISE OF THE 'PORCUPINE' (Plate 6).

Station No.	North Latitude.	West Longitude.	Depth in Fathoms.	Surface Temperature, Fahrenheit.	Bottom Temperature, Fahrenheit.
46.	59° 23′	7° 4′	374	53°·9	46°·0
47.	59 34	7 18	542	54·0	43·8
48.	59 32	6 59	540	...	...
49.	59 43	7 40	475	53·6	45·4
50.	59 54	7 52	355	52·6	46·2
51.	60 6	8 14	440	51·6	42·0
52.	60 25	8 10	384	52·1	30·6
53.	60 25	7 26	490	52·1	30·0
54.	59 56	6 27	363	52·5	31·4
55.	60 4	6 19	605	52·6	29·8
56.	60 2	6 11	480	52·6	30·7
57.	60 14	6 17	632	52·0	30·5
58.	60 21	6 51	540	51·4	30·8
59.	60 21	5 41	580	52·7	29·7
60.	61 3	5 58	167	49·5	44·3
61.	62 1	5 19	114	50·4	45·0
62.	61 59	4 38	125	49·6	44·6
63.	61 57	4 2	317	49·0	30·3
64.	61 21	3 44	640	49·7	30·0
65.	61 10	2 21	345	52·0	30·0
66.	61 15	1 44	267	52·4	45·7
67.	60 32	0 29	64	51·9	49·1
68.	60 23	0 33 E.	75	52·5	44·0
69.	60 1	0 18 E.	67	53·5	43·8
70.	60 4	0 21	66	53·4	45·1
71.	60 17	2 53	103	53·0	48·6
72.	60 20	3 5	76	52·3	48·8
73.	60 29	3 6	84	52·7	48·8
74.	60 39	3 9	203	52·6	47·6
75.	60 45	3 6	250	51·5	41·9
76.	60 36	3 58	344	50·3	29·7
77.	60 34	4 40	560	50·9	29·8
78.	60 14	4 30	290	52·2	41·5
79.	59 44	4 44	76	52·1	48·9
80.	59 49	4 42	92	53·2	49·4
81.	59 54	5 1	142	53·3	49·1
82.	60 0	5 13	312	52·3	41·4
83.	60 6	5 8	362	53·1	37·5
84.	59 34	6 34	155	54·3	49·1
85.	59 40	6 34	190	53·9	48·6
86.	59 48	6 31	445	53·6	30·1
87.	59 35	9 11	767	52·5	41·4
88.	59 26	8 23	705	53·5	42·6
89.	59 38	7 46	445	53·1	45·5
90.	59 41	7 34	458	53·1	45·2
VI.	60 45	4 49	510	52	31·7
VII.	60 7	5 21	500	51	30·2
VIII.	60 10	5 59	550	53	29·8
X.	60 28	6 55	500	51	30·8
XI.	60 30	7 16	450	50	31·2
XII.	59 36	7 20	530	52·5	44·8
XIV.	59 59	9 15	650	53	42·5
XV.	60 38	11 7	570	52	43·5
XVII.	59 49	12 36	620	52	43·5


NORTH PACIFIC OCEAN
SEA OF KAMTSCHATKA
KAMTSCHATKA
SEA OF OKOTSK
Behring's Str.
SIBERIA
Liakhov I.
NORTH AMERICA
Banks Str.
Melville Sound
Wellington Ch.
Boothia G.
Barrow's Str.
Smith Str.
ARCTIC OCEAN
Hudson's Bay
Fox Chan.
Hudson's Str.
Baffins Bay
Davis Str.
GREENLAND
Spitzbergen
Nova Zembla
LABRADOR
Gulf of St. Lawrence
NEW FOUND LAND
Lapland
Iceland
Finland
Faroe Islands
NORWAY
SWEDEN
Baltic Sea
NORTH ATLANTIC OCEAN
BRITISH ISLES
IRELAND
North Sea
RUSSIA
EUROPE
130° 140° 150° 160° 170° 180° 170° 160° 150°
120° 110° 100° 90° 80° 70° 60° 50°
40° 30° 20° 10° 0 10° 20° 30°

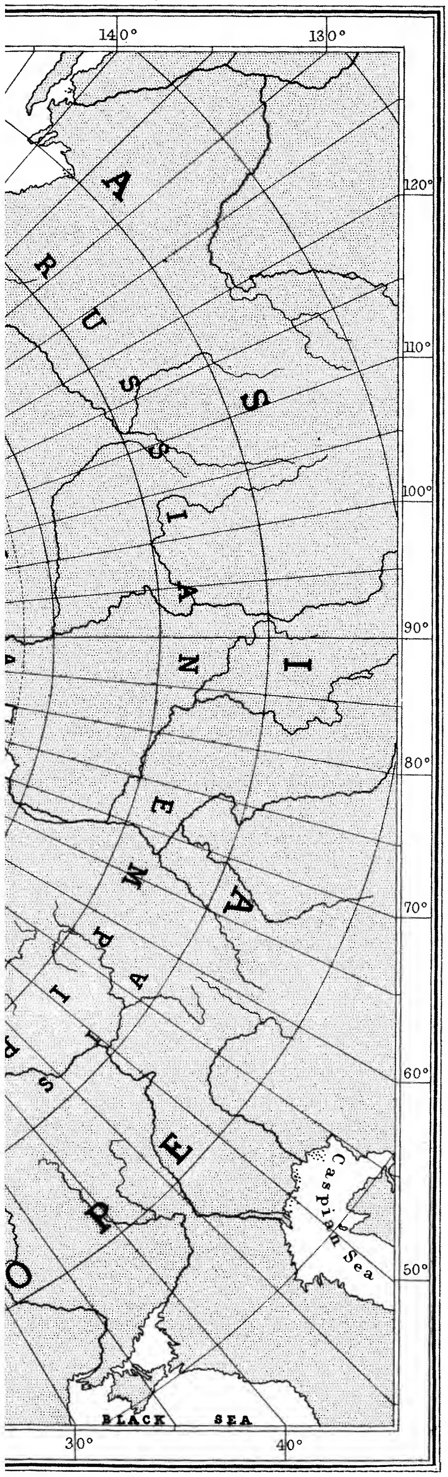

140°
130°
120°
110°
100°
90°
80°
70°
60°
50°
30°
40°
RUSSIA
ASIATIC RUSSIA
EUROPEAN RUSSIA
Caspian Sea
BLACK SEA

Fig. 1.

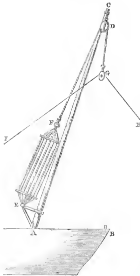


Fig. 2.

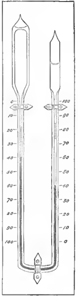
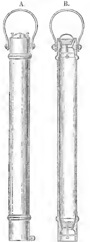


Fig. 3.



Water-Bottle as seen at A externally, and at B in section; drawn to a scale of *one-eighth* the actual size.

Fig. 4.

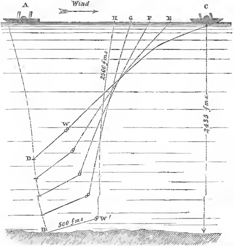
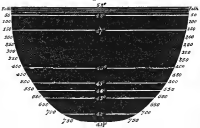


Diagram I.



52°
Fath
Fath
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
48°
47°
46°
45°
44°
43°
42°
41½°

Diagram II.

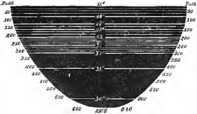

Fath
Fath
50
100
150
200
250
300
350
400
450
500
550
600
640
29°6
640

Diagram III.—Curves constructed from Serial Soundings in the Warm and Cold Areas, the Depths being represented by the *vertical* lines, and the Degrees of Fahrenheit's Thermometer by the *horizontal* lines.

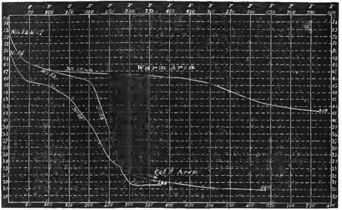


Diagram IV.—Curves constructed from Bottom-soundings in the Warm, Cold, and Intermediate Areas.

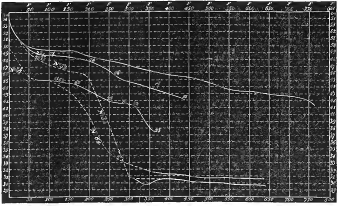
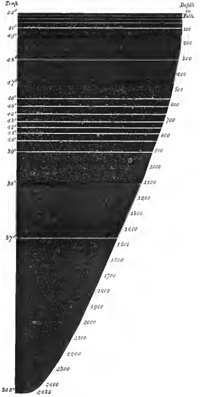
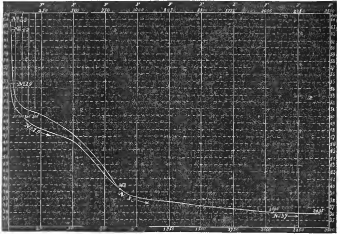


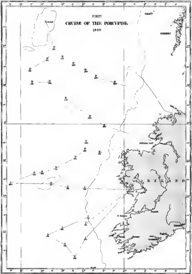
Diagram V.

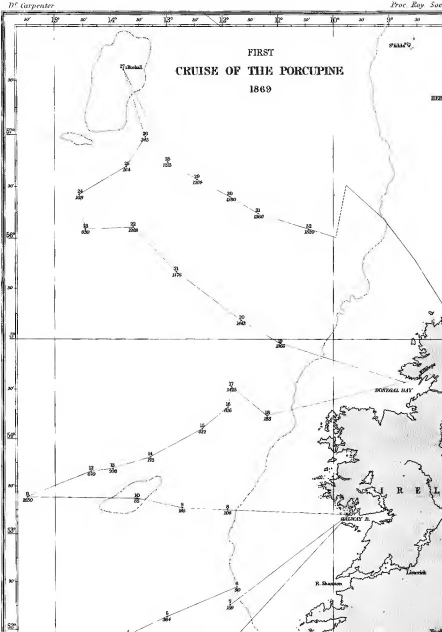


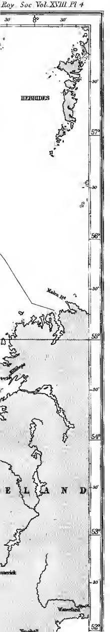
Temp.
Depth in Fath.
54°
50°
49°
48°
47°
46°
45°
44°
43°
42°
41°
40°
39°
38°
37°
30.5°
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2435

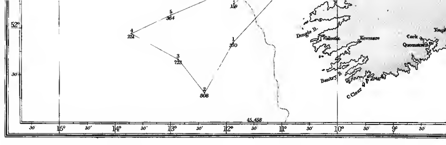
Diagram VI.—Curves constructed from Serial Soundings in the Atlantic Basin.



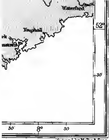

FIRST
CRUISE OF THE PORCUPINE
1869
IRELAND


FIRST
CRUISE OF THE PORCUPINE
1869
27 Rockall
St Kilda
HEB
DONEGAL BAY
Killibegs
GALWAY B.
I R E L
R. Shannon
Limerick
26 345
25 164
24 109
28 1215
29 1264
30 1380
31 1360
32 1320
23 630
22 1268
21 1476
20 1443
19 1366
17 1425
16 816
18 183
15 422
14 173
12 670
13 208
11 1630
10 85
9 165
8 106
6 90
7 159
5 364
15°
14°
13°
12°
11°
10°
9°
57°
56°
54°
53°
52°

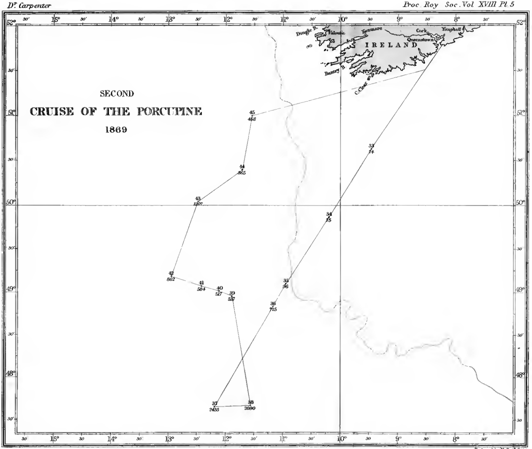

30'
8°
30'
HEBRIDES
57°
56°
Malin Hd
55°
54°
E L A N D
53°
Waterford
52°



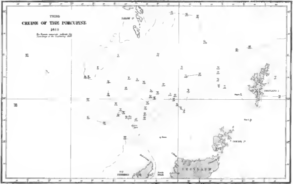
52°
30
5
364
4
251
3
723
2
808
1
370
159
Dingle B.
Valentia
Kenmare
Cork
Queenstown
Youghal
Bantry B.
C. Clear
45,458
30
15°
30′
14°
30′
13°
30′
12°
30
11°
30′
10°
30′
9°
30′



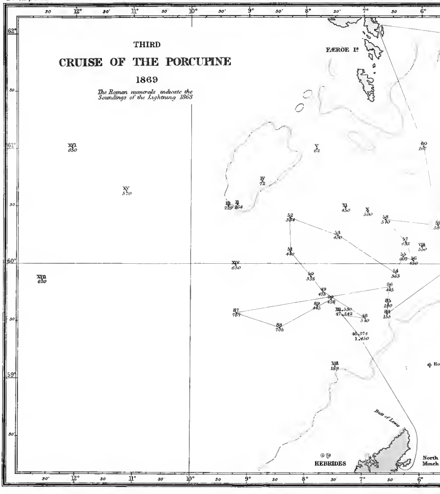
Engraved by Malby & Sons

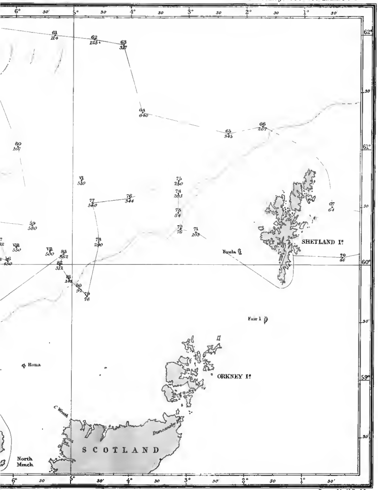


Engraved by Malby & Sons


THIRD
CRUISE OF THE PORCUPINE
1869
FAROE Is
SHETLAND I.
ORKNEY Is
SCOTLAND
HEBRIDES
North Minch

Dr. Carpenter





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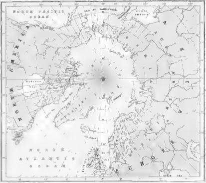
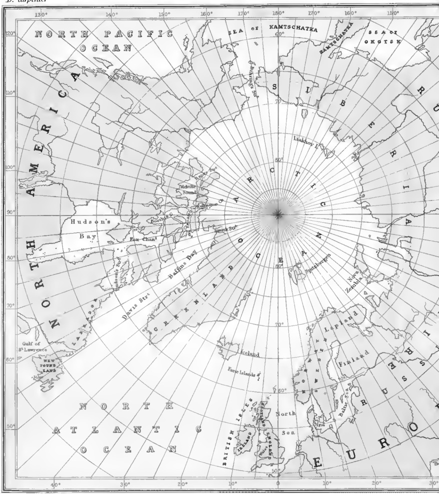
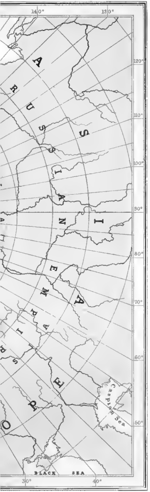

NORTH PACIFIC OCEAN
SEA OF KAMTSCHATKA
NORTH AMERICA
ASIA
NORTH ATLANTIC OCEAN
EUROPE

Dr. Carpenter




140°
130°
120°
110°
100°
90°
80°
70°
60°
50°
Caspian Sea
BLACK SEA
30°
40°